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Evaluation of Pacific sardine (*Sardinops sagax*) stock assessment and harvest guidelines in British Columbia

Évaluation des stocks de sardine du Pacifique (*Sardinops sagax*) et lignes directrices concernant les prélèvements en Colombie-Britannique

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ABSTRACT

Proportions of the Pacific sardine (*Sardinops sagax*) population off North America annually migrate from southern waters (mainly off California) where they spawn during late winter and spring to northern waters, such as off British Columbia, where they forage during summer and autumn, returning south late in the autumn. The sardine population collapsed to very low levels in the mid-20th century, disappearing altogether from Canadian waters. A coast-wide recovery of the stock began in the 1980s. The Canadian sardine fishery has harvested sardines experimentally since 1995 and commercially since they were declared not at risk by COSEWIC in 2002.

The recent Canadian Pacific sardine harvest framework has been based on an annually updated biomass estimate of the adult coastwide population from the U.S. assessment and an annually updated migration rate estimate of sardines into Canadian waters, upon which a harvest rate equivalent to the U.S. rate has been applied (a 15% Canadian harvest rate has been in place since 2002). Representatives of Canadian sardine industry have shown interest in developing a harvest policy independent of the U.S stock assessment that favours using a British Columbia seasonal estimate of sardine biomass resulting from a summer research trawl survey.

This report provides: 1) updated estimates of regional biomass and seasonal migration for the west coast of Vancouver Island from trawl survey data; 2) additional sardine biomass and migration rate estimates from extrapolating WCVI trawl survey sardine densities to other areas of the B.C. coast where sardines are frequently observed; 3) provisional maximum harvest options for the 2011 fishing season resulting from applying the previously approved harvest control rule with updated estimates of the mean seasonal migration rate (2008-2010), the recent estimate of the coastwide population from the U.S. stock assessment and a 15% harvest rate ; 4) provisional maximum harvest options for the 2011 fishing season resulting from applying an alternative harvest control rule, which is based solely on seasonal estimates of sardine biomass in B.C. waters and a 15% harvest rate; and 5) background information related to biological concerns and information gaps that should be considered when setting catch allowances in B.C. waters.

Mean sardine survey catch density and biomass estimates for the WCVI survey region declined from 2006 to 2010, as did biomass estimates for the coastwide adult population. Estimates of migration for 2008 to 2010 into the WCVI survey region were 22.9%, 27.8% and 15.3% and estimates of migration into the inshore areas outside of the WCVI survey region were 4.7%, 5.7% and 3.2 %. The 2008-2010 mean migration rate estimate was 22.0% for the WCVI survey region, 4.6% for the inshore areas outside of the WCVI survey region, and 27.2% for both areas combined. Applying these updated mean migration rate estimates to the previously accepted Canadian harvest control rule along with the recent (2010) coastwide adult sardine biomass estimate of 537,173 tonnes and a 15% harvest rate, maximum harvest options equate to 17,725 tonnes (based on WCVI survey region migration estimates), or 21,917 tonnes (based on WCVI survey region and inshore areas combined migration estimates). An alternative harvest control rule that is based on B.C. biomass estimates and a 15% harvest rate generates maximum harvest options of 12,295 tonnes (based on WCVI survey region biomass estimates), or 14,838 tonnes (based on WCVI survey region and inshore areas combined biomass estimates). This second and alternative harvest control rule has the drawback of being

completely dependent on completion of a summer survey and has equal or greater risk of overshooting the target regional harvest rate when regional biomass decreases between years. Variability in regional and coastwide estimates of 2006-2010 realized harvest rates reflects changes in assessment methods and fishing effort in Canada and the U.S. Simulated harvest control rule scenarios for both nations show how harvest rates for the coastwide population can exceed a common target rate. Length and age trends from biological samples collected in coastal regions of B.C. and the U.S. show seasonal and regional variability relevant to stock structure and effects of strong and weak year classes, in particular the lack of a relatively strong year class since 2005.

RÉSUMÉ

Certaines parties de la population de sardine du Pacifique (*Sardinops sagax*) observées au large de l'Amérique du Nord migrent entre le sud (principalement au large de la Californie) où elles fraient à la fin de l'hiver et au printemps et le nord, comme au large de la Colombie-Britannique, où elles s'alimentent pendant l'été et l'automne avant de retourner au sud, à la fin de l'automne. La population de sardines s'est effondrée pour atteindre de très faibles niveaux au milieu du XX^{e} siècle et est complètement disparue des eaux canadiennes. Le rétablissement du stock de l'ensemble de la côte a débuté dans les années 1980. Au Canada, une pêche expérimentale à la sardine a cours depuis 1995 et, depuis 2002, date à laquelle le COSEPAC a déclaré que l'espèce n'était pas en péril, on pratique une pêche commerciale visant cette espèce.

Le récent cadre canadien pour la pêche à la sardine du Pacifique repose sur une estimation de la biomasse adulte de l'ensemble de la côte mise à jour annuellement et dérivée de l'évaluation américaine ainsi que sur une estimation du taux de migration des sardines dans les eaux canadiennes également mise à jour chaque année, pour laquelle on a appliqué un taux de prélèvement équivalent à celui des États-Unis (un taux de prélèvement de 15 % est utilisé depuis 2002). Les représentants de l'industrie canadienne de la sardine ont démontré de l'intérêt à l'égard de l'élaboration d'une politique sur les prélèvements indépendante de l'évaluation des stocks des États-Unis qui favoriserait l'utilisation d'une estimation saisonnière de la biomasse des sardines en Colombie-Britannique dérivée de relevés scientifiques au chalut effectués au cours de l'été.

Le présent rapport contient : 1) des estimations à jour de la biomasse régionale et de la migration saisonnière pour la côte ouest de l'île de Vancouver fondées sur les données de relevés au chalut; 2) des estimations supplémentaires de la biomasse et du taux de migration des sardines établies par extrapolation des densités de sardines dérivées des relevés au chalut sur la COIV à d'autres zones de la côte de la C.-B. où l'espèce est souvent observée; 3) des options de prélèvements maximaux provisoires pour la saison de pêche 2011 découlant de l'application de la règle de contrôle de la pêche approuvée auparavant ainsi que des estimations à jour du taux de migration saisonnier moyen (2008-2010), l'estimation récente de la population de l'ensemble de la côte fondée sur l'évaluation américaine des stocks et un taux de prélèvement de 15 %; 4) des options de prélèvements maximaux provisoires pour la saison de pêche 2011 obtenues avec l'application d'une autre règle de contrôle de la pêche, laquelle ne repose que sur des estimations saisonnières de la biomasse des sardines dans les eaux de la C.-B. et un taux de prélèvement de 15 %; 5) des renseignements de base concernant les préoccupations d'ordre biologique et les lacunes dans l'information qui doivent être prises en considération au moment de l'établissement des attributions de prises.

Les estimations de la biomasse et de la densité moyennes des prises dérivées du relevé des sardines effectué dans le secteur de la COIV ont décliné de 2006 à 2010, tout comme les estimations de la biomasse adulte de l'ensemble de la côte. Dans le secteur couvert par les relevés de la COIV, les estimations de la migration de 2008 à 2010 étaient de 22,9, 27,8 et 15,3 %, et les estimations de la migration dans les zones côtières situées à l'extérieur du secteur couvert par les relevés de la COIV étaient de 4,7, 5,7 et 3,2 %. L'estimation du taux de migration moyen de 2008-2010 était de 22,0 % dans le secteur couvert par le relevé de la COIV, de 4,6 % dans les zones côtières situées à l'extérieur du secteur couvert par le relevé de la COIV et de 27,2 % dans les deux secteurs combinées. Lorsqu'on applique ces estimations du taux de migration moyen à jour à la règle canadienne de contrôle des pêches acceptée auparavant avec l'estimation récente (2010) de la biomasse adulte de l'ensemble de la côte de 537 173 tonnes ainsi qu'à un taux de prélèvement de 15 %, les options relatives aux prélèvements maximaux sont de 17 725 tonnes (selon les estimations de la migration dans le secteur couvert par les relevés de la COIV) ou de 21 917 tonnes (selon les estimations de la migration dans le secteur couvert par les relevés de la COIV et dans les zones

côtières combinés). Une autre règle de contrôle de la pêche, reposant sur les estimations de la biomasse en C.-B. et un taux de prélèvement de 15 %, produit des options de prélèvements maximaux de 12 295 tonnes (selon les estimations de la biomasse dans le secteur couvert par les relevés de la COIV) ou de 14 838 tonnes (selon les estimations de la biomasse dans le secteur couvert par les relevés de la COIV et dans les zones côtières combinés). Cependant, cette deuxième règle de contrôle de la pêche exige la réalisation d'un relevé d'été, et le risque de dépasser le taux de prélèvement régional cible lorsque la biomasse régionale diminue d'une année à l'autre est équivalent ou supérieur. La variabilité observée dans les estimations des taux de prélèvement réalisés en 2006-2010 pour l'ensemble de la côte et pour chaque région témoigne des changements effectués dans les méthodes d'évaluation et l'effort de pêche consenti au Canada et aux États-Unis. Les scénarios de règles de contrôle de la pêche pour les deux pays démontrent que les taux de prélèvement pour la population de l'ensemble de la côte peuvent dépasser un taux cible commun. Les tendances en matière de longueur et d'âge dérivées des échantillons biologiques recueillis dans les régions côtières de la C.-B. et des É-U. révèlent une variabilité saisonnière et régionale par rapport à la structure du stock et aux effets de classes d'âge abondantes et peu abondantes, particulièrement l'absence de classes d'âges relativement fortes depuis 2005.

INTRODUCTION

The Pacific sardine (*Sardinops sagax*) is a pelagic schooling fish that, when abundant, occupies coastal waters from Baja California to southeast Alaska (Hill et al. 2007). The Pacific sardine population has been shown to undergo long term cycles in abundance having disappeared from much of the west coast of North America in the late 1940s and not reappearing until the early 1980s (Hill et al. 2007). In winter and spring months, most of the sardine population resides in waters off the California coast (Hill et al 2010). In summer, sardines migrate northward, but migratory patterns can be affected by population size and oceanographic conditions. As the population has recovered in the north-east Pacific, its distribution has expanded and has resumed annual northward migrations to the Pacific northwest and Canada (Hargreaves et al. 1994, McFarlane and Beamish 2001). The timing of the northward migration mirrors that which was observed in the 1930s and appears to be constrained by water temperature, particularly the 12°C isotherm (Ware 2001).

The most recent framework for setting annual allowable catch of Pacific sardine in British Columbia (B.C.) waters results from regional advisory processes conducted in 1999, 2001, and 2009 (DFO 1999; Ware 1999; DFO 2001; Schweigert and McFarlane 2001; DFO 2009; Schweigert et al 2009). The framework is based on three factors: 1) current coastwide sardine biomass estimates conducted by United States (U.S.) analysts (DFO 1999; Ware 1999; DFO 2001, Schweigert and McFarlane 2001), 2) the adoption of an annual harvest rate equivalent to what is applied in the U.S., which first occurred for the 2002 B.C. fishing season (DFO 2001; Schweigert and McFarlane 2001) and has been 15% in recent years but is a function of sea surface temperature and U.S. harvest control rules (Hill et al. 2010); and, 3) the application of an estimated rolling average seasonal migration rate of sardines into B.C. waters (DFO 2009; Schweigert et al. 2009), derived from dividing estimates of seasonal sardine abundance in B.C. waters (west coast of Vancouver Island observations) by estimates of the coastwide population biomass (coastwide stock assessment results, e.g. Hill et al. 2008).

Ware (1999) estimated that the mean migration rate into Canadian waters was 10 percent based on historical fishery landings prior to the 1950s. A 2009 analysis of west coast of Vancouver Island (WCVI) summer surface trawl survey data representing the years 1997 to 2008 substantiates why the previously assumed mean seasonal migration rate of 10% was updated to 18.3% for the 2009 fishing season (DFO 2009; Schweigert et al. 2009). For the 2010 fishing season, the mean migration rate was updated to 22% to represent the three most recent survey years of 2006, 2008 and 2009 (DFO 2010).

Based on perceived changes in stock size and migration and increased commercial fishing interest, sardine harvests in B.C. waters have increased in recent years (from ~1,550 to 20,000 tonnes from 2006 to 2010, Table 1). As the Canadian Pacific sardine fishery has expanded, representatives of the sardine industry have proposed that additional biomass should be estimated for sardine distribution outside of the WCVI survey region. Industry representatives have also proposed that a new harvest policy be considered based primarily on regional estimates of biomass in Canadian waters and that is independent of annual U.S. stock assessment results.

The principle objectives of this report were to:

1) Provide updated estimates of regional sardine biomass and seasonal migration rates for the WCVI from trawl survey data;

2) Provide additional sardine biomass and migration rate estimates by extrapolating trawl survey densities to other areas of the B.C. coast where sardines are frequently observed;

3) Provide options for setting maximum harvests for the 2011 fishing season calculated from applying updated estimates of mean seasonal migration (2008-2010) to the previously approved harvest control rule, which incorporates a recent estimate of the coastwide population from the U.S. stock assessment;

4) Provide options for setting maximum harvests for the 2011 fishing season calculated from applying an alternative harvest control rule, which is based solely on seasonal estimates of sardine biomass in B.C. waters, thus independent of the U.S. stock assessment, and,

5) Identify biological concerns and information gaps that should be considered when setting harvest allowances in B.C. waters.

This report also includes information on: the U.S. Harvest Guideline (harvest control rule); annual total allowable catch (TAC) amounts and estimates of realized harvest rates from fisheries in Canada, the U.S. and both countries combined; results representing simulated transboundary harvest control rule scenarios; and length and age distributions from commercial and research samples collected in different regions and seasons of the sardine population's occurrence.

METHODS

WCVI SAMPLING

In order to analyse sardine survey catch density data to annually estimate regional abundance and migration, a core WCVI summer survey region was defined and only data from the most recent survey years were applied. To identify the boundaries of a core region intended to represent typical summer sardine habitat off the WCVI, sardine survey catch densities for 1997-2010 were plotted within 4x4 km grid cells. A total of 875 trawl tows were included, 428 of which caught sardines. The western and northern boundaries of the core survey region were delineated where sardine catch was low (<10 tonnes/km^3) and a southern boundary was defined as the Canada-U.S. border. Of the 428 positive trawl tows, 366 or 86% represented waters directly west of WCVI headlands and within outer boundaries delineated on Figure 1. These outer boundaries were used to define a core survey region. The core region extends approximately 75 km from shore parallel to the U.S. border and tapers northward to 30 km off the northwest corner of Vancouver Island and encompasses an area of 16,740.08 km^2. Inlets are not included within the core survey region because of sampling constraints. Daytime surveys occurred almost annually from 1997 through 2005 but these data were somewhat experimental; furthermore, daytime sardine behaviour is thought to have confounded some data sets so these years were omitted from further analysis. Trawl sampling occurred at night during mid-summer periods of 2006 and 2008-2010 (no survey conducted in 2007) and data from these years were most applicable to current assessment considerations.

Figure 2 shows sampling locations and relative catch densities of sardine for the 2006, and 2008 to 2010 WCVI surveys. For all years, night trawl sampling locations off the WCVI core survey region included transect lines and random spot sampling. For the 2010 survey, tow locations were randomly selected prior to the survey to minimize bias affecting biomass estimates (for example, sampling along environmental gradients). The 2010 survey design was based on a 10x10 km mapped grid extending approximately 2 to 52 km from shore with a range in latitude of 50.7°N to 48.5°N, extending southward to within 10 km of the U.S. border. Grid intersections represented the population of possible sampling stations and sampling effort was distributed evenly across a latitudinal gradient, by assuming that approximately 75 stations would be sampled over 11 nights.

Each year, sampling occurred during late July to early August, spanning 8, 10, 15 and 11 nights for 2006 and 2008-2010 survey years, respectively and acoustics were not used to target or detect schools for fishing purposes. Sampling generally occurred from north to south to minimize the possibility of fishing the same schools more than once during northward migrations. For all four surveys, the research vessel W.E. Ricker (a 57.3 m steel stern trawler) was deployed, towing a model 250/350/14 mid water rope trawl (Cantrawl Pacific Ltd., Richmond, B. C.) in surface waters (< 30 m deep). Tow speeds and distances typically ranged from 4.5 to 5.5 knots (8.3 to 10.2 km/hour) and 3.0 to 5.0 km, respectively. Catch sizes up to approximately 1.5 tonnes were sorted by species and total weight of fresh sardines was measured at sea using a motion compensated scale, whereas for larger catch sizes, total amounts were visually estimated by the fishing master and a representative sample of the mixed catch was sorted and weighed by species. Subsequently, the proportion of the subsample comprised of sardine was extrapolated to estimate the amount of sardines in the total catch. For each tow, a measure of catch density (t/km^3) was calculated based on the total weight of sardines in a tow divided by an estimate of the volume of water swept during the fishing event. Estimates of swept volumes were determined by multiplying the length and width of the trawl net by the effective fishing distance covered during a tow. The width of the trawl net was typically ~ 32 m and the net height was typically 12-14 m. Sampling locations outside of the core region's outer boundaries were omitted from analyses for estimating catch density, biomass and migration.

SURVEY TRAWL DENSITIES

By survey year, frequency distributions of sardine catch densities and summary statistics were generated and bootstrapping (Efron, 1981) was used to estimate 95% confidence intervals of mean sardine densities by year. A simple (naïve) bootstrap approach was applied to generate means from simple random samples, with replacement, using a sample size equal to the observed sample repeated 2000 times to simulate a distribution of mean values. The lower and upper confidence limits were estimated from the 50th and 1950th values in the sorted distribution of simulated means.

BIOMASS

A biomass estimate for the WCVI core survey region was calculated for each year as the product of the mean catch density (t/km^3) and the volume of the region. Throughout the core survey region, catch densities were assumed to represent an average vertical distribution of 30 m. Therefore, based on the total area of the core survey region (16,740.08 km^2), the regional volume was estimated to be 502.2 km^3. A 95% confidence interval of the regional biomass estimate was derived by multiplying each of the lower and upper mean catch density confidence limit by the regional surface volume.

To estimate biomass outside of the core survey region for years 2006, 2008 to 2010, mean sardine catch densities from WCVI trawl survey data were extrapolated to inshore areas outside of the WCVI survey region for which there are records of sardine occurrence from commercial purse seine fishing activity. In recent years, a significant proportion of the commercial purse seine catch was harvested from inlets of the WCVI and protected waters north of the survey region. To identify and define the inshore areas for representation by extrapolation, information on commercial sardine seine catch amounts and catch locations was compiled for June to August 31st of 2006 to 2010 to identify areas inhabited by sardines immediately before, during and after trawl sampling in the WCVI region (Table 1). The cumulative list includes 10 Fisheries and Oceans Canada (DFO) Pacific Fishery Management Areas (PFMAs) and 46 Sub-Areas. The 10 PFMAs are 7, 8, 9, 10, 12, 23, 24, 25, 26 and 27 (Figure 3). Areas and Sub-Areas within the boundaries of the WCVI core survey region (e.g. PFMA 123) were excluded. The total area of the 46 Sub-Areas is approximately 3,465 km^2. Annual biomass for the combined PFMA Sub-Areas was estimated by assuming that mean mid-summer WCVI night density estimates are representative of those occurring in inshore fishing areas and that average night vertical distributions for all these inshore areas was 30 m. The combined spatial volume of this entire inshore

area (denoted as IA) was estimated at 103.9 km^3, which was multiplied by each of the 2006-2010 WCVI survey mean sardine density estimates to estimate biomass outside of the core region.

MIGRATION

Migration rate is estimated as the proportion of the coastwide (Mexico, U.S. and B.C. waters) adult sardine stock that occurs mid-summer in B.C. waters. For any given year, the migration rate is calculated as the ratio of the B.C. summer biomass estimate and the coastwide summer biomass estimate of adult sardines (1 year old and older and denoted as 1+) determined from the annual U.S. stock assessment. Migration rate was estimated for the WCVI core survey region, the inshore area, and for the two areas combined.

For forecasting abundance applicable to the harvest control rule (described below), a running average migration rate for the three most recent years was calculated, which is consistent with what was proposed in Schweigert et al (2009) and DFO (2009). We calculated the mean of the 2008-2010 migration rate estimates for the WCVI core survey region, the inshore area, and for both areas combined for consideration in setting harvest allowances for the 2011 fishing season.

CANADIAN HARVEST CONTROL RULE

The B.C. sardine harvest control rule (HCR) was first proposed by Ware (1999) and updated by Schweigert et al. (2009) and includes three terms, the product of which has been used to provide advice on recommended maximum harvest options for the management of sardines. The terms are:

1. An estimate of the total coastwide (Mexico, U.S. and Canada) adult biomass (1+) for semester 1 (July 1-Dec 31) in the most recent year from the U.S. coastwide stock assessment (i.e. Hill et al. 2010). The coastwide biomass estimate for semester 1 of 2010 was 537,173 tonnes.

2. A running average of B.C. mid-summer sardine migration rate using the three most recent trawl survey estimates.

3. A target harvest rate, which has been fixed at the U.S harvest rate adopted during the current season and has been 0.15 since 1990.

The product of the first two terms is used as a biomass forecast for the following summer. To calculate amounts representing provisional maximum harvest options for the 2011/2012 fishing season, the means of the 2008-2010 migration rate estimates for the WCVI core survey region and for the WCVI core survey region combined with the inshore area were applied to harvest control rule calculations. Inclusion of the biomass estimates for inshore areas in the migration term is novel to the assessment process and the harvest control rule.

ALTERNATIVE TO CURRENT CANADIAN HARVEST CONTROL RULE

Representatives of the Canadian sardine industry have expressed concern about some of the assumptions implicit in the U.S. stock assessment methods and the resulting biomass estimates. As a consequence, they have supported the development of a localized assessment based on a biomass estimate for Canadian waters. This alternative harvest control rule would eliminate the use of a coastwide biomass estimate from the U.S. stock assessment and instead rely solely on a B.C. seasonal biomass estimate. To model how this alternative harvest control rule would work, each of the current biomass estimates for the WCVI core survey region and for the WCVI core survey region and inshore area combined was multiplied by 0.15 (representing a 15% harvest rate) to simulate TAC options that are modeled as TAC amounts for the following fishing year. For demonstration purposes,

it was assumed that 100 % of the simulated TAC was caught each year (realized annual harvests were equal to the TAC). The ratio between each simulated TAC and the respective regional biomass estimate represents a simulated harvest rate. Since the WCVI survey time series is discontinuous, a 2007 biomass estimate was linearly interpolated so that the time series could be based on 2006-2010 biomass estimates to simulate the 2007 to 2011 fishing seasons.

U.S. HARVEST GUIDELINE

The existing U.S. sardine harvest control rule has a "Harvest Guideline" that has been in use since 2000 to provide advice on maximum harvest amounts for the management of sardines. This Harvest Guideline consists of four terms (Hill et al. 2010) and the equation for annually determining the U.S. Harvest Guideline is:

Harvest Guideline = (Biomass - Cutoff) x Fraction x Distribution

where

Harvest Guideline (tonnes) = Total allowable catch option (all states combined)
Biomass (tonnes) = An estimate of the total coastwide adult biomass (1+) for semester 1 (July 1-Dec 31) of the most recent year
Cut-off = Lowest biomass where harvest is allowed (currently 150,000 tonnes);
Fraction = Maximum sustainable yield (MSY) control rule for the proportion of stock to be harvested;
Distribution = proportion of stock biomass assumed to reside in U.S. waters and not lost to Mexico (set at 0.87).

The Fraction term is a proxy for Fmsy, which is a modelled fishing mortality rate approximating a maximum sustainable yield. Fmsy and sardine productivity were determined to be a function of sea surface temperature as follows:

$$\text{Fraction (or Fmsy)} = 0.249\,T^2 - 8.19\,T + 67.46$$

where T is the average sea surface temperature (°C) at Scripps Pier, California during the preceding three seasons. Fraction (Fmsy) is constrained to range between 5% and 15%.
Based on ocean conditions since 1990, the harvest rate "fraction" has remained at 15%.

The Distribution term represents the assumption that there is an average net loss of 13% of the coastwide biomass to Mexican waters (through migration and mortality) and thus 87% remains under U.S. jurisdiction. Distribution to Canadian waters is not accounted for.

REALIZED HARVEST RATES

The 2006 to 2010 sardine TAC amounts, harvests and estimates of realized harvest rates from Canadian and U.S. fisheries were compiled. TACs were based on nationally applied harvest control rules for each country and year. Realized harvests were obtained from DFO and U.S. catch records (i.e. DFO 2010, Hill et al 2010). Estimates of realized harvest rates were calculated by dividing harvest amounts by Canadian or coastwide biomass estimates. Abundance estimates for the WCVI core survey region and for the WCVI core survey region and inshore area combined are presented.

TRANSBOUNDARY HARVEST CONTROL RULE SCENARIOS

To demonstrate how the algebraic relationship between the U.S. and Canadian harvest control rules influences coastwide net harvest rates, scenarios were simulated where both nations individually apply a 15% target harvest rate on adult age 1+ sardine. The following three variables were modified in the set of scenarios:

1) Coastwide adult biomass (varying from 300,000 to 3,000,000 tonnes)
2) B.C. migration (20%, 40% and 60 %)
3) Including or omitting the U.S. cut-off of 150,000 tonnes

The U.S. Distribution factor of 87% was applied to all modelling scenarios. For each scenario, a TAC and harvest rate was modelled by country and collectively for the two countries.

LENGTH AND AGE

Sardine length and age data from survey or commercial samples collected in B.C, Washington, Oregon and California are included in this report to illustrate some seasonal and regional trends in stock structure of the sardine population. Abundance trends of 1 year old (age-1) recruits to the spawning population (by year class) from the most recent U.S. coastwide stock assessment (Hill et al. 2010) are included to characterize aspects of stock structure.

Length (fork) and age (year) information from WCVI summer research surveys during 2003-2006 and 2008-2010 and from inshore commercial seine catches collected during July-October of 2004 and 2007 are presented. By year, pooled sample sizes ranged from 232 to 569 fish, and represented 5 to 11 fishing events. Ageing was done by one of four technicians trained in surface reading of sardine otoliths. This ageing method is reliable for ages up to 4 but from age-5 onwards there is a tendency to underage fish due to difficulties in distinguishing annular rings (McFarlane et al. 2010,).

Length and age trends from B.C. catch samples collected during 2003-2010 were compared with length trends reported in Lo et al. (2009, 2010) and length, age and age-1 recruitment trends reported in Hill et al. (2010). Comparisons were made between near-shore commercial purse seine fishery samples collected during summer or spring months from Washington and Oregon waters; near-shore commercial purse seine fishery samples collected during summer or spring months from California waters; research trawl samples collected during summer or spring months from Washington and Oregon; and research trawl samples collected during spring months from California. Age estimates reported in Hill et al. (2010) for the PNW and California commercial purse seine catches were based on pre-determined length-age relationships rather than determined directly from reading otoliths from the catch samples.

RESULTS

SURVEY TRAWL DENSITIES

The mean survey trawl sardine catch density estimates for the WCVI core survey region decreased from 759 t/km^3 in 2006 to163 t/km^3 in 2010 (Table 2). The number of tows that occurred within the core survey region were 44, 60, 95 and 57 for the 2006 and 2008-2010 surveys, respectively. The proportion of tows with sardines was relatively similar in 2008 to 2010 (range = 0.49-0.67) but considerably higher in 2006 (0.93; Table 2). Sardine catch densities greater than 3,000 t/km^3 occurred in the 2006, 2008, and 2009 surveys, whereas, no catch densities were greater than 3,000 t/km^3 in the 2010 survey (Figure 4).

BIOMASS

Biomass estimates for the WCVI core survey region and the inshore area decreased during 2006 to 2010 (Table 3, Figure 5). The WCVI core survey region 2006 biomass estimate was 381,617 tonnes (95%CI = 231,816 - 555,232), the 2008 estimate was 210,924 tonnes (95%CI= 98,682-369,820), the 2009 estimate was 189,977 tonnes (95%CI= 28,927-155,541) and the 2010 estimate was 81,964 tonnes (95%CI = 28,927 - 155,541).

Inclusion of the inshore area for estimating biomass results in a 20.7% increase relative to the estimate for the WCVI core region. The inshore area 2006 biomass estimate was 78,953 tonnes (95% CI = 47,960 - 114,872), the 2008 estimate was 43,638 tonnes (95%CI=20,416-76,512), the 2009 estimate was 39,304 tonnes (95%CI= 22,880-57,955) and the 2010 estimate was 16,958 tonnes (95%CI = 5,985 - 32,180). The list of PFMAs and Sub-areas represented by the entire inshore area is shown in Table 4 along with size estimates of PFMA groupings used to derive biomass estimates.

Coastwide biomass estimates decreased during 2006 to 2010 (Table 3, Figure 6). The 2006 biomass estimate was 1,248,410 tonnes (95%CI = 743,970 - 1,752,850) and the 2010 estimate was 537,173 tonnes (95% CI = 257,993 – 816,353). During 2006-2010, biomass estimates for the coastwide population decreased linearly with a mean annual rate of decline of approximately 188,000 tonnes (R^2 =0.99, p = 0.003, F= 364, Figure 6). There was also a significant linear relationship between WCVI biomass and coastwide biomass estimates (R^2 =0.94, p = 0.03, F= 31; Figure 7).

MIGRATION

Migration rate estimates for 2006 and 2009 were relatively similar and considerably higher than estimates for 2010, whereas the estimate for 2008 was intermediate (Table 3, Figure 8). Migration rate estimates for the WCVI core survey region for 2006 and 2008-2010 were 30.6; 22.9; 27.8 and 15.3 per cent, respectively, with a mean of 22.0% for 2008-2010. Combined migration rate estimates for the WCVI core survey region and the inshore area in 2006 and 2008-2010 were: 36.9; 27.7; 33.5 and 18.4 %, respectively, with a mean of 27.2 % for 2008-2010.

CANADIAN HARVEST CONTROL RULE

Results from applying the most recent estimate of coastwide adult sardine biomass (537,173 tonnes for semester 1 of 2010), a 15% harvest rate and the mean of the 2008-2010 migration rate estimates to current Canadian harvest control rule framework are provided in Table 5. The provisional maximum harvest option calculated from the mean migration rate estimate for the WCVI core survey region (22.0%) is 17,725 tonnes. The provisional maximum harvest option calculated from the mean migration rate estimate for the WCVI core region and the inshore area combined (27.2%) is 21,917 tonnes.

ALTERNATIVE TO CURRENT CANADIAN HARVEST CONTROL RULE

Using an alternative harvest control rule, based solely on a 15% harvest rate of the 2006-2010 biomass estimates for either the WCVI core survey region or the core region and the inshore area combined, simulated results show that modelled annual catches (set to equal TACs) continuously decrease over the modelled time series of 2007-2010, from 57,243 to 12,295 tonnes, and from 69,085 to 14,838 tonnes, respectively (Table 6). The range in modelled harvest rates was 16.6-34.8%, which exceeds the target of 15%. Modelled harvest rates are greatest (i.e. 24.6% and 34.8%) when the relative decline between two consecutive biomass estimates is greatest (i.e. 2007-2008 and 2009-2010). Conversely, harvest rates would undershoot the target when biomass increases considerably between consecutive years.

REALIZED HARVEST RATES

Observed 2006-2010 TACs, harvests and estimates of Canadian and coastwide abundances are shown in Table 7 and estimates of corresponding realized harvest rates are shown in Table 8. Estimates of realized Canadian harvest rates, based on abundance for the WCVI core survey region and for the WCVI core survey region and inshore area combined, collectively ranged from 0.3% to 24.4%. Estimates of realized Canadian harvest rates, based on the coastwide abundance ranged from 0.1% to 3.7%. Estimates of realized harvest rates for Washington and Oregon combined, based on coastwide abundance, ranged from 3.2% to 6.0%, whereas estimates for the Pacific Northwest (B.C., Washington and Oregon combined) ranged from 3.3% to 9.7%. Estimates of realized coastwide harvest rates (U.S.+B.C.), based on coastwide abundance, ranged from 7.4% to 15.5%. Estimates of realized harvest rates for all U.S. harvests, based on coastwide abundance, ranged from 7.3% to 11.8%. Realized proportions of annual TACs varied from approximately 8% to over 86% for Canada and from approximately 76% to approximately 100% for the U.S.

TRANSBOUNDARY HARVEST CONTROL RULE SCENARIOS

Results from the simulated scenarios of varying coastwide biomass, annual migration rate into Canada and the inclusion or omission of the U.S. biomass cut-off demonstrate how the combination of the current U.S. and Canadian harvest control rules can result in a collective coastwide harvest rate that exceeds each country's target level perceived to be15% (Table 9). The effect is evident when migration into Canada is relatively high or when the coastwide population is relatively high, and compounded when both conditions occur. The effect of relatively high migration into Canada is based on the fact that neither country accounts for the other country's fishing pressure and sardine that migrate into Canadian waters are susceptible to capture by both nations in a given fishing season. The effect of relatively high coastwide population is due to the fact that as the population size increases, the relative difference between it and the cut-off (150,000 tonnes) decreases. This simply demonstrates how the cut-off buffers the population on a sliding scale.

LENGTH AND AGE

The 2003 year class showed the greatest contribution to the coastwide population in over 10 years and the 2004 and 2005 year classes also had relatively high recruitment; whereas the 2006-2009 year classes had relatively low recruitment (Hill et al, 2010, Figure 9).

Fork length and age data of sardine samples collected from B.C. waters in 2003-2010 show sequential shifts in distribution patterns between years from ageing of year classes (Figure 10). The modal fork length of sardines collected in 2003 and 2004 is 25-26 and 26 cm, respectively. Fish collected in 2005 show two distinct modes at 20-21 cm and 26 cm. The modal fork length of sardines collected in 2006 and 2007 is 22 cm, whereas the modal fork length for 2008-2010 samples is 23 cm; in 2010, there were also smaller fish with a modal length of 14 cm. For the 2003 fish, most fish were aged at 5 and 6 years and for 2004 most fish were aged at 6 and 7 years; whereas for 2005 the peak age was 2 years (the 2003 year class) and this year class appeared to be predominant in 2006 (as age 3), in 2007 (as age 4), in 2008 (as age 5) and in 2010 (as age 7). For 2009, the predominant fish age is reported to be 5.

Lo et al. (2010) report standard length distributions of sardines from research trawl samples and commercial purse seine samples collected off Washington-Oregon or Central-Southern California coasts in July of 2003 and 2004 and spring (March-April) of 2004 and 2005 (Figure 11 of this report). Their results show that samples collected in July from Washington-Oregon had larger fish (170-280mm) than samples collected in July from California (110-180mm); whereas samples collected in the spring from California had larger fish (in 2004, 2005) and approximately the same size fish (in

2005) compared to samples collected in the spring from Washington-Oregon. Furthermore, Lo et al. (2010) also found length distributions to be notably different between research trawl and commercial seine samples collected from approximately the same latitude and season. Specifically, fish from California spring 2004 purse seine samples were smaller than fish from California research trawl samples; conversely, fish from Washington-Oregon July 2004 purse seine samples were larger than fish from Washington-Oregon research trawl samples.

Length distributions of fish collected in research trawls off Central and Southern California during 2008 and 2009 spring spawning seasons (that are associated with the U.S. coastwide assessment's Daily Egg Production Method survey) show standard lengths ranging from 160-260mm and lacking in relatively small fish symbolic of new recruits (Figure 12).

Results from Hill et al. (2010, Figures 13-15 of this report) show sardine length and age trends representing inshore purse seine samples collected off the PNW and central and southern California. Samples collected in 1999-2009 from B.C., Washington and Oregon combined, show that fish were typically in the range of 17-26 cm standard length (equivalent to 19-29 cm fork length) and results from length-age models suggest that these fish varied in ages from 2-8 years (Figure 13). Results from commercial purse seine samples collected over the same years (and earlier) from Southern and Central California show that most fish were in the range of 10-20 cm standard length (equivalent to 11-23 cm fork length) and results from length-age models suggest that these fish varied in ages from 1-4 years (Figures 14-15).

DISCUSSION

The Pacific sardine population on the west coast of North America is a transboundary resource that has seasonal migrations from southern spawning regions off California and Mexico to feeding regions off northwest U.S. and southwest Canada. The timing of the annual northward migration and its intensity (i.e. proportion of the adult population) are governed by environmental factors that are not well understood. As a result, co-ordinating annual assessment surveys in time and space to determine population abundance in either spawning or feeding regions is challenging. The annual trawl survey off the west coast of Vancouver Island is aimed at providing a repeatable and representative assessment of regional sardine abundance and demographic composition in Canadian waters at a time when northward migration may be near its peak. As such, survey biomass estimates can be perceived as minimum seasonal estimates (in Canadian waters) since the survey does not extend to other areas of the B.C. coast. In the current report, we attempted to account for biomass outside of the survey region through extrapolation methods. Future development of survey techniques will be required to more accurately assess sardine distribution, abundance and stock composition in Canadian waters.

SURVEY TRAWL DENSITIES

Trawl survey design is based intended to cover the potential longitudinal and latitudinal distributions of sardine off the WCVI each year. Sardine mean density estimates decreased over the WCVI core survey time series but their CVs (ranging from 0.23 to 0.39) indicate a relatively high degree of variability and uncertainty, a feature common to trawl surveys. Through simulation, Schnute and Haigh (2003) show how trawl samples with relatively large CVs and high proportions of zero catches are especially susceptible to bias but increasing sample size improves the quality of estimates. Unfortunately, survey resources are limited so sample sizes of future surveys will likely remain comparable to the 2008 to 2010 surveys. For all survey years, large portions of the region went unsampled and this is especially the case for 2006, which had very few observations near the offshore boundaries, the smallest sample size, and the largest density estimates. The relatively low CV for the

2006 data is related to the high proportion of tows with sardines in the catch (93%). All other survey years had lower portions of tows with sardines and lower catch densities overall, especially 2010 (Figure 2). Lo et al. (2010) reported biomass estimates from four surface trawl surveys off Oregon and Washington to have CVs ranging from 0.38 to 1.00 for sampling intensities that were lower or comparable to those applied in the WCVI core region, but Lo et al. (2010) also applied inshore and offshore stratification to their methods. Future work using WCVI trawl densities should explore stratification schemes that reduce CVs to improve mean density estimates. Tentative sub-regions have been delineated within the core survey region for this purpose (Figure 1, Appendix A)

It is generally assumed that the trawl net has complete catchability of sardines encountered along the towing path. It is currently not possible to evaluate this assumption or the assumption that, on average, the vertical density and distribution of sardine is accurately represented within the upper 30 m throughout the WCVI survey region. Direct or inverse relationships may occur between school density, school vertical distribution and surface trawl catchability. Relationships between these factors may vary within the region and within a season as well as between seasons and relationships cannot be assessed or characterized without directed studies. Ongoing acoustic studies by U.S. scientists may clarify some of these factors that could then be incorporated into future assessments, including relationships with SST and isocline depths. Nevertheless, the trawl survey estimates of biomass enable the indexing of sardine biomass in Canadian waters, which is a tool for developing harvest guidelines for fishery management in conjunction with other information, such as related to stock composition.

BIOMASS AND MIGRATION

A decrease in estimated biomass over the WCVI trawl survey time series was evident but migration rate estimates did not show the same pattern (Figures 5 and 8). The decrease in estimated biomass can be due to a decrease in biomass of the coastwide population and/or a change in the distribution and migration patterns. The high correlation between the WCVI survey biomass estimates and the coastwide estimates suggests a decline in biomass rather than a change in migration. The decrease in sardine abundance since 2006 is unlikely due to over-fishing but is most probably attributed to poor recruitment and changing oceanographic conditions and food availability (Emmett et al. 2005; MacFarlane et al. 2005). Emmett et al (2005) found a positive relationship between sardine catch densities and sea surface temperature (SST) as well as chlorophyll *a*. Based on sardine length distributions and seasonal abundance patterns over a 1998-2004 time series, they deduced that adult sardines foraging in PNW waters in summer and autumn months migrate south to California during winter months and generally do not reoccur in PNW waters until SST exceeds 12°C, such as in June and July. This conclusion is consistent with the trend in WCVI migration rate estimates and the fact that 2006 and 2008 were the coldest summers in the time series (http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/sst-tsm/index-eng.htm) and correspond to the lowest migration rate estimates (Figure 8).

The WCVI survey provides a midsummer snapshot of the relative abundance of sardines off the west Coast Vancouver Island and cannot provide information on in-season variation in abundance or distribution. Studies conducted in Oregon and Washington, which consisted of multiple surveys annually, demonstrated how seasonal abundance and distribution in the PNW can vary within and between years (Emmett et al. 2005, Lo et al. 2010). Northwest Marine Fisheries Science Center surveys off Oregon and Washington from 1998 to 2004 found considerably lower occurrences of sardines in May than in June and July for all years except 1998, which was an extreme El Nino year (Emmett et al. 2005). Results from these surveys also show that between June and July, relative abundance was generally greatest in July, although there was one year (2001) when June abundance was higher and one year (2004) when abundance for both months was similar.

INSHORE AREA BIOMASS

To estimate sardine biomass for areas outside of the trawl survey region, we made assumptions about sardine density and the spatial distribution of sardine occurrence. The total inshore area included in the analysis represents commercial fishing areas that are thought to be typical inshore summer sardine habitat. These areas have commercial importance for several reasons, including 1) sardines show some predictability in their presence and general distribution within or near these areas, 2) the areas are in relatively sheltered waters amenable to purse seining and, 3) the areas are relatively close to landing sites. The predictability of sardine occurrence in these inshore areas is probably based on the fact that the areas are adjacent to, and/or part of, migration corridors as well as being terminal foraging grounds with high levels of food availability. Habitat features of these inshore areas that would enhance plankton growth and forage productivity include tidal mixing of nutrients from land and relatively warm surface waters. We did not adjust the surface volume of the inshore area for portions where depths were less than 30m, thus the total inshore surface volume was overestimated.

There were significant differences in commercial fishing locations between years. During June-August of 2008 and 2009, the majority of fish caught were from waters east and north of Vancouver Island (PFMA 7- 12), whereas in 2010, the majority of fish caught were from the WCVI inlets (PFMA 23-27, Table 1). By inshore PFMA grouping, the June-August catches (handled not retained) are considerably less than biomass estimates, with the exception of those representing the WCVI inshore areas in 2010 (Tables 1 and 4). However, the catches represent a three month period and fish can move in and out of the inshore areas during this time. Combined effects of fleet behaviour and predictability of fish movement can confound the interpretation of catch effort which can be insensitive to changes in stock abundance.

In future years, it will be important to capture information on sardine distribution to evaluate the assumptions associated with estimating biomass outside of the trawl survey region. Further discussion of how the spatial scale can be evaluated will be required. Otherwise we suggest that the spatial representation of 103.9 km^3 (for 3,464.7 km^2) associated with extrapolation of trawl survey densities not be increased for subsequent assessments. Development of aerial survey methodology was initiated in 2009 and may be developed and implemented within the next few years to provide estimates of density inside and outside of the trawl survey region.

ALTERNATIVES TO CANADIAN HARVEST CONTROL RULE

The reported modelled results corresponding to the application of an alternative Canadian harvest control rule which sets TACs based on previously observed estimates of abundance and a 15% harvest rate show how the tendency to exceed the target harvest rate continues for each year the population is perceived to decline. The trend in error (difference between target and observed) would be reversed if abundance was perceived to steadily increase between years. Furthermore, error can compound over two or more years with a common directional trend (i.e. 2007-2008 and 2009-2010 modelled in Table 6) and error could be further compounded if the mean abundance for two or more years was used to set TACs. It appears that the degree of risk associated with this type of harvest control rule (of exceeding or under-achieving the target harvest rate) would be similar to the currently applied harvest control rule since both control rules forecast amounts based on past seasons creating a time lag in the annual representation for setting a TAC. However, in the event that the trawl survey is unavailable to obtain a local estimate of seasonal abundance, this alternative harvest control rule could not be applied.

In addition to the harvest control rules described so far, there are other options worth considering in the future. We provide examples of two other methods for setting TACs, neither of which require annual biomass estimates from directed surveys. One option would be to assume some benchmark

level of seasonal migration over an inter-annual period (i.e. 3 years) and to set annual TACs based on the product of this benchmark migration and the recent coastwide estimate of adult biomass from the U.S. stock assessment. This approach is fairly similar to the current harvest control rule and may be required in the future should survey resources become unavailable, as has happened in the past (i.e. 2007). Applying a migration benchmark also translates directly into a benchmark harvest rate on a coastwide scale. Results shown on Table 8 suggest that the Canadian fishery in 2010 and the combined Washington and Oregon fisheries in 2006-2009 each had realized coastwide harvest rates of approximately 3 - 4%. As such, a benchmark coastwide harvest rate of ~ 3% for the B.C. fishery could be used to set the TAC.

Another harvest control option is to set the TAC as a constant for a predetermined number of years. The management of sardines in South Australia has a fixed TAC policy which came about after rigorous and coordinated effort into studying ecosystem impacts and economic viability (Shanks 2005, PIRSA 2009). There, the fixed TAC is 34,000 t and is modelled to achieve long term harvest rates ranging between 10 and 20%. The ranges in population size and spatial distributions are smaller in the Australian sardine population without the complexity of multiple nations accessing the resource. Therefore, determining a fixed harvest rate for the Canadian fishery may prove to be more difficult.

REALIZED HARVEST RATES AND TRANSBOUNDARY EFFECTS

In B.C., realized harvest rate estimates increased from 2006 to 2010 whereas in the U.S, they remained relatively stable from 2006 to 2009. These trends are a function of changes in TAC and fishing effort (Tables 7 and 8). On a coastwide scale, the 2010 B.C. harvest rate (3.7%) was comparable to the 2006-2009 estimates for Washington and Oregon combined (3.3 - 6.3%) but the 2010 harvest rate for Washington and Oregon increased to 9.7%. There are several reasons to explain why realized harvest rates for 2010 are greater than estimates for 2006-2009. With respect to coastwide abundance, the main reason for the low 2006-2009 harvest rates is that the stock assessment methodology changed in 2009. Prior to 2009, biomass estimates for the U.S. coastwide assessment were calibrated solely by spring escapement sampling off California (based on egg, larvae and spawner observations) from two separate indices referred to as the Daily Egg Production Model (DEPM) and Total Egg Production (TEP, Hill et al. 2008). Due to concerns that these indices were overly conservative, summer aerial surveys were initiated to provide an independent population abundance estimate. There was a large discrepancy in 2009 between observations from the spring escapement survey and the summer aerial survey (Table 10, Hill et al. 2009 and 2010, Jagielo et al. 2009). Consequently, all abundance estimates for past years were scaled upwards following a recalibration. Since the modelled TACs of previous years were based on past abundance estimates, the current view of coastwide abundance makes past harvest rates appear considerably lower.

With respect to abundance in Canada, there are five reasons for the low 2006-2009 harvest rates relative to the high 2010 harvest rate reported on Table 8. The first is that fishing effort was relatively low in 2006 and 2007 compared to the TACs (Tables 1 and 7). The second reason is that in 2009, the coastwide abundance increased substantially from the recalibration using aerial survey data (explained above). The third reason is due to a change in how B.C. abundance forecasts were estimated. Up until 2008, the forecasting method applied a 10% migration rate to coastwide biomass estimates from the U.S. assessment (Ware 1999) and WCVI survey data were first applied to harvest control rule outcomes (DFO 2009, Schweigert 2009). The fourth reason is that the current method of estimating biomass from the WCVI survey is somewhat different from what was done for the 2009 and 2010 fishing seasons and the current estimates are greater than previously calculated and reported (Schweigert et al. 2009, DFO 2010). There were two changes made to the interpretation of the WCVI survey data for the current assessment which affected mean annual density and biomass estimates for past years. The first was the redefinition of the regional boundaries (Figure 1) and the second was the elimination of the stratification scheme previously used to delineate the region. Finally, the fifth

reason for the relatively high harvest rate in 2010 is due to increased fishing effort to provide product to meet increasing market demand.

Current annual estimates of coastwide realized harvest rates for Canada and the U.S. combined suggest that despite the U.S. cut-off of 150,000 tonnes, in 2010, the net harvest rate may have exceeded 15%. Simulated results in Table 9 show how combined effects of each nation's harvest control rule can exceed the common target harvest rate of 15% under conditions of high abundance and/or high migration into Canada, but the simulations do not characterize error or uncertainty associated with estimating biomass or forecasting abundance. Coastwide biomass estimates have CVs that range from 0.4-0.5 (Hill et al 2010) and WCVI biomass estimates have CVs that range from 1.5-3.0 (Table 2), thus, there is considerable uncertainty with estimates presented in Table 3, especially those representing migration, for which we have not estimated 95% confidence intervals (Figure 8). Furthermore, both countries apply a harvest control rule that sets the TACs on observed biomass estimates for a past period, therefore when abundance decreases between years (such as what appears to have happened from 2006 to 2010) then the combined effect of over forecasting may supersede the buffering effect of the U.S. cut-off. The coastwide stock assessment also generates a forecast of spawning stock biomass (SSB) for the upcoming spring, which is closer in time to the start of the Canadian fishing season. Since 2009, SSB forecasts have been calibrated by the results of the aerial survey estimates (both the 2009 and 2010 survey results) and age structure updates (based on growth and mortality functions). SSB forecasts assume a Ricker stock-recruitment relationship which is not necessarily an accurate predictor of recruitment. Nevertheless, we note that the SSB forecast for the spring of 2011 is 376,250 t, which is considerably less than the summer 2010 biomass estimate of 537,173 t. Projected spring SSB (January to June) rather than the estimate for the previous summer's Semester 1 (July-December) Age 1+ biomass estimate warrants future consideration associated with future Canadian harvest control applications.

The U.S. Harvest Guideline applies an assumed 87% distribution factor which represents long term average distributions of a 13% net loss from portions of the population inhabiting Mexican waters and 87% of the population remaining in U.S waters. These factors were based on weighted averages of spotter pilot and ichthyoplankton surveys (~1960s to early 1990s) conducted during ecological conditions when sardine biomass levels were low to moderate (Pacific Fishery Management Council, 1998). If net loss to Mexico annually exceeds 13%, then the 87% U.S. distribution factor could have a positive bias on U.S. assessment coastwide biomass estimates and U.S. Harvest Guideline results. The U.S. distribution factor of 87% was never intended to relate to migration into Canada.

LENGTH AND AGE

Sampling of the coastwide sardine population has shown different size and age structures for different regions and seasons of its distribution (Emmett et al. 2005, Lo et al. 2010 and Hill et al. 2010). Length and age trends representing sardines caught in B.C. waters in 2003-2010 compared to sardines caught in Oregon and Washington trawl survey and purse seine samples show some strong similarities (Figures 10, 11 and13). The 2009 year class observed in the WCVI 2010 samples may be from a relatively local spawning event and it is not uncommon to find sexually active sardines in PNW waters during spring and summer months (McFarlane et al. 2005, Lo et al. 2010). By year and season, differences in length distributions between PNW and California samples demonstrate segregation of age and size classes between latitudinal regions and longitudinal proximity to shore (Figures 11, 13-15). Both Emmett et al. (2005) and Lo et al. (2010) deduced that the presence of large sardines caught during summer trawl surveys off Oregon summer and autumn commercial seine fisheries off Oregon spring commercial fisheries off California is consistent with the concept that these fish migrate between southern California and the PNW. The strong 2003 year class appears to have had some predominance in research trawl and commercial purse seine samples collected during 2005-2010 from B.C., Washington, Oregon and California (Figures 10-15).

There is uncertainty about the biological role of the relatively large and old sardines found in B.C. and the PNW and their biological link to sardines in other regions in terms of their migratory behaviour, size segregation and reproductive contribution to the population, which both Emmett et al. 2005 and Lo et al. 2010 also acknowledge. The reproductive contribution (i.e. gross annual fecundity) of large sardines is much greater than small sardines, especially from cumulative effects of multiple batch spawning events throughout a season (Lo et al. 2009). Furthermore, migratory contingents may have phenotypic or behavioural traits that make the stock more robust to recovery following periods of depletion (Petitgas et al. 2010). Petitgas et al. (2010) caution that fishery management that concentrates only on biomass could easily overshadow the need for structural diversity that confers a population's capability to rebuild and exploit the full range of suitable habitats. They highlight that monitoring a population's status should also include monitoring the spatial contingents and intercontingent connectivity.

It can be difficult to follow older year classes in the population when ageing sardines by surface reading of otoliths because of the potential for bias from under-estimating fish older than 4 years. This may account for why the 2009 and 2010 WCVI age distribution patterns appear sequentially out of phase with each other. Furthermore, ageing errors can bias results from length-age models (i.e. Hill et al. 2010, Figures 13-15), therefore modelled ages representing older fish in all regions are suspect of error with unknown uncertainty. Results from ageing sardines from analysing otoliths are thought to be improved when incorporating an otolith polishing treatment which is more labour intensive than simple surface reading (McFarlane et al 2010). Future work and resources would be required to incorporate polished otolith protocols into assessment efforts in both Canada and in the U.S.

HARVEST ADVICE

Depending on the acceptability of the revised sardine biomass estimates for B.C. waters (subject to review), we present 4 provisional maximum harvest options for the 2011/12 fishing season resulting from either the existing or alternative HCR frameworks.

Using the previously endorsed HCR:

1) A maximum harvest of 17,725 tonnes, based on the 2010 estimate of coastwide biomass (537,173 tonnes), an updated migration rate based on migration estimates for the WCVI core survey region (22.0%), and a 15% harvest rate.
2) A maximum harvest of 21,917 tonnes, based on the 2010 estimate of coastwide biomass (537,173 tonnes), an updated migration rate based on migration estimates for the WCVI core survey region and inshore areas combined (27.2%), and a 15% harvest rate.

Using an alternative B.C. biomass based HCR:

3) A maximum harvest of 12,295 tonnes, based on the 2010 WCVI core survey region biomass estimate (81,964 tonnes) and a 15% harvest rate.
4) A maximum harvest of 14,838 tonnes, based on the 2010 WCVI core survey region and inshore areas combined biomass estimate (98,922 tonnes), and a 15% harvest rate.

FUTURE WORK

There are several directions where future work is planned or anticipated. Future work pertaining directly to assessing sardine annual abundance and migration in B.C. waters includes continued WCVI sampling efforts in the core region to maintain a fishery independent time series. Future WCVI survey work should investigate methods to reduce CVs associated with density and biomass estimates, such as through stratification schemes. We propose a sampling scheme with proportional sampling intensity in 8 sub-regions (delineated in Figure 1) so that variability in sardine distribution and

density can be investigated by latitude and longitude (which includes varying depths and proximity to shore). Additionally, post stratification schemes can be considered, using trawl site water temperature information. The application of binomial-gamma distribution models to represent sardine trawl data to estimate parameters, such as the proportion of non-zero catches, the mean and quartiles, also looks promising and deserves additional investigation. Major changes to coastwide assessment methods are being considered for upcoming years which would influence biomass and migration estimates in the time series and subsequent forecasts. When such changes are made, further consideration should be given to combined effects of U.S. and Canadian harvest control rules and whether the Canadian harvest control rule should continue to apply a forecast based on a coastwide semester 1 biomass estimate, the coastwide forecast for SSB, or some other estimate. We also recognize the importance of ageing sardines and the uncertainty of ageing older fish. We recommend that future work be directed at characterizing sardine ages using polished otolith methods (to reduce uncertainty associated with ageing methods (McFarlane et al. 2010), and analysing fish length and age trends from both survey and commercial catch data.

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REFERENCES

DFO 1999. Report of the Pacific Scientific Advice Review Committee (PSARC) Pelagic Subcommittee meeting November 16,1999. DFO Can Sci. Advis. Sec. Proceed. Ser. 1999/31.

DFO 2001. Report of the Pacific Scientific Advice Review Committee (PSARC) Pelagic Subcommittee meeting November 19-20, 2001. DFO Can Sci. Advis. Sec. Proceed. Ser. 2001/31.

DFO. 2009. Proceedings of the Pacific Scientific Advice Review Committee (PSARC) meeting for the assessment of scientific information to estimate Pacific sardine seasonal migration into Canadian waters. DFO Can.Sci. Advis.Sec. Proceed. Ser. 2009/034.

DFO. 2010. Pacific Sardine Integrated Fisheries Management Plan 2010/2011. Government of Canada. (http://www.dfo-mpo.gc.ca/Library/340775.pdf)

Efron, B. 1981. Nonparametric estimates of standard error: The jackknife, the bootstrap and other methods. Biometrika, 68: 589-599.

Emmett, R.L., Brodeur, R.D., Miller, T.W., Pool, S.S., Krutzikowsky, G.K., Bentley, P.J., McCrae, J. 2005. Pacific sardine (*Sardinops sagax*) abundance, distribution, and ecological relationships in the Pacific northwest. CalCOFI Rep. 46:122-143.

Hargreaves, N.B., Ware, D.M. and McFarlane, G.A. 1994. Return of the Pacific sardine *(Sardinops sagax)* to the British Columbia coast in 1992. Can. J. Fish. Aquat. Sci. 51: 460-463.

Hill, K.T., Dorval, E. Lo, N.C.H., Macewicz, B.J.,Show, C., and Felix-Uraga, R. 2007. Assessment of the Pacific sardine resource in 2007 for U.S. management in 2008. NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFSC-413, 183 p.

Hill, K.T., Dorval, E. Lo, N.C.H., Macewicz, B.J.,Show, C., and Felix-Uraga, R. 2008. Assessment of the Pacific sardine resource in 2008 for U.S. management in 2009. Pacific Fishery Management Council, Nov 2008 Briefing Book, Agenda Item G.2.b. Supplemental Attachment 1. 147 p.

Hill, K. T., Lo, N.C.H.,Crone, P.R., Macewicz, B.J. and Felix-Uraga, R. 2009. Assessment of the Pacific sardine resource in 2009 for USA management in 2010. Pacific Fishery Management Council, Nov 2009 Briefing Book, Agenda Item I.1.b. Attachment 2. 241 p.

Hill, K.T., Lo, N.C.H., Macewicz, B.J., Crone P.R. and Felix-Uraga, R. 2010. Assessment of the Pacific sardine resource in 2010 for U.S. management in 2011. Pacific Fishery Management Council, Nov 2010 Briefing Book, Agenda Item I.2.b. Attachment 2. 128 p.

Jagielo, T.J., Hanan, D. and Howe, R. 2009. West Coast Aerial Sardine Survey. Sampling Results in 2009. Prepared for California Wetfish Producers Association, and the Northwest Sardine Survey. Submitted to Pacific Fishery Management Council, Portland, OR, October 14, 2009.

Lo, N.C.H., Macewicz, B.J., and Griffiths, D. 2010. Biomass and reproduction of Pacific sardine (*Sardinops sagax*) off the Pacific northwestern United States 2003-2005. Fishery Bulletin 108: 174-192.

Lo, N. C. H., Macewicz ,B.J., and Griffith D. 2009. Spawning biomass of Pacific sardine (*Sardinop sagax*) off California in 2009. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFSC-449, 31 pp.

McFarlane, G.A., and Beamish, R.J. 2001. The re-occurrence of sardines off British Columbia characterises the dynamic nature of regimes. Prog. in Oceanog. 49: 151-165.

McFarlane, G.A., Schweigert, J., MacDougall, L., and Hrabok, C. 2005. Distribution and biology of Pacific sardines (*Sardinops sagax*) off British Columbia, Canada. CalCOFI Sci. Rep. 46: 144-160.

McFarlane, G.A., Schweigert, J., Hodes, V. and Detering, J. 2010. Preliminary study on the use of polished otoliths in the age determination of Pacific sardine (*Sardinops sagax*) in British Columbia waters. CalCOFI Res. Rep. 51: 162-168.

Pacific Fishery Management Council 1998. .December 1998 Fishery Management Plan Amendment 8, Appendix B: Options and Analyses for the Coastal Pelagic Species Fishery Management Plan. http://www.pcouncil.org/coastal-pelagic-species/fishery-management-plan-and-amendments/

Petitgas, P., Secor, D.H., McQuinn, I., Huse, G., and Lo, N. 2010. Stock collapses and their recovery: mechanisms that establish and maintain life-cycle closure in space and time ICES J. Mar. Sci. (2010) 67(9): 1841-1848

Primary Industries and Resources South Australia (PIRSA) Fisheries Division. 2009. Ecological Assessment of the South Australian Sardines (*Sardinops sagax*) Fishery (Reassessment Report). South Australian Fisheries Management Series (July 2009), 22p.

Schnute, J.T., and Haigh, R. 2003. A simulation model for designing groundfish trawl surveys. Can. J. Fish. Aquat. Sci. 60: 640-656.

Schweigert, J. and McFarlane, G.A. 2001. Stock assessment and recommended harvest for Pacific Sardine in 2002. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/126. 12p

Schweigert, J., McFarlane, G.A., and Hodes, V. 2009. Pacific sardine (*Sardinops sagax*) biomass and migration rates in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/088. 14p.

Shanks, S. 2005. Management Plan for the South Australian Pilchard Fishery. South Australian Fisheries Management Series 47, 54p.

Ware, D.M. 1999. Life history of Pacific sardine and a suggested framework for determining a B.C. catch quota. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/204.

Ware, D.M. 2001. Forecasting the time of arrival and availability of Pacific sardine in British Columbia. Unpublished manuscript prepared for DFO and B.C. Sardine Association. 22p.

Table 1. Summary information on Pacific sardine purse seine fishing effort in B.C. for June1-August 31 of 2006-2010. All catch amounts by Pacific Fishery Management Area (PFMA) are in tonnes (t).

ANNUAL TOTAL			JUNE 1- AUGUST 31 INSHORE FISHING EFFORT BY YEAR AND PFMA						
Year	TAC(t)	Realized catch (t)	PFMA	No. of Sub-areas*	Area km^2	In-season catch (t)+	No. of sets	Mean catch (t /set)	Proportion 0 catch
2006	13,500	1,558	12	2	378.0	473.0	25	18.9	0.24
2007	19,800	1,524	7	1		40.0	3	13.3	0.00
			9	1		22.7	2	11.3	0.00
			12	12		985.0	63	15.6	0.21
			23	2		108.5	13	8.3	0.08
			All	16	1,546.0	1,156.2	81	14.3	0.17
2008	12,491	10,435	8	2		416.3	16	26.0	0.06
			9	1		10.0	1	10.0	0.00
			10	4		324.0	7	46.3	0.00
			12	6		4,146.0	139	29.8	0.26
			25	5		406.0	35	11.6	0.26
			26	4		617.0	37	16.7	0.05
			All	22	1,771.1	5,919.3	235	25.2	0.20
2009	18,196	15,334	8	3		706.1	27	26.2	0.30
			9	4		2,425.4	90	26.9	0.17
			10	9		1,754.0	67	26.2	0.19
			12	1		122.0	2	61.0	0.00
			23	7		1,730.2	106	16.3	0.24
			24	1		55.0	1	55.0	0.00
			25	4		1,493.7	79	18.9	0.16
			All	29	2,111.7	8,286.4	372	22.3	0.20
2010	23,166	20,000	8	2		30.0	2	15.0	0.50
			9	4		2,527.0	91	27.8	0.09
			10	3		776.0	36	21.6	0.06
			12	1		203.0	5	40.6	0.20
			23	8		2,295.0	99	23.2	0.16
			25	7		5,083.0	212	24.0	0.04
			26	1		36.0	1	36.0	0.00
			27	1		67.0	3	22.3	0.33
			All	27	1,563.5	11,017.0	449	24.5	0.08

*- Count of Sub-Areas provided instead of individual Sub-Areas to protect the confidentiality of fishers (i.e., the "3 party rule").

+- To show presence of sardines, in-season catch (t) represents all fish handled, not all retained.

Table 2. Summary information and statistics associated with West Coast Vancouver Island (WCVI) trawl survey sardine catch densities. Effective sample sizes represent samples within the core region. For 95% confidence interval, LL= lower limit and UL= upper limit.

YEAR	2006	2008	2009	2010
WCVI SAMPLING				
Tows with sardines / total number of tows	42/45	44/71	53/109	40/72
Core survey region Tows with sardines/ total number of tows	41/44	40/60	47/95	37/57
Core survey region proportions of tows with sardine	0.93	0.67	0.49	0.65
SARDINE DENSITY (t/km^3)				
Mean	759.9	420.0	378.3	163.2
95% LL	461.6	196.5	220.2	57.6
95% UL	1,105.6	736.4	557.8	309.7
SD	1,148.1	1,062.5	852.9	484.9
SE	173.1	137.2	87.5	64.2
CV	0.23	0.33	0.23	0.39
QUARTILES (t/km^3)				
Min	0.00	0.00	0.00	0
Q.25	14.5	0.0	0.0	0.0
Median	211.0	4.3	0.0	1.0
Q.75	1,139.1	420.2	394.9	71.8
Max	5,686.8	7,173.0	4,570.0	2,951.0

Table 3. Estimates of sardine biomass in the WCVI core survey region, inshore area, both areas combined, and coastwide (Mexico, U.S. and Canada) biomass and corresponding estimates of seasonal migration rate for 2006-2010. For 95% confidence interval, LL= lower limit and UL= upper limit.

	YEAR	2006	2007	2008	2009	2010	2008-2010
BIOMASS (tonnes)							**Mean**
WCVI							
	Mean	381,617		210,924	189,977	81,964	160,955
	95% LL	231,816		98,682	110,589	28,927	79,399
	95% UL	555,232		369,820	280,127	155,541	268,496
Inshore							
	Mean	78,953		43,638	39,304	16,958	33,300
	95% LL	47,960		20,416	22,880	5,985	16,427
	95% UL	114,872		76,512	57,955	32,180	55,549
WCVI + Inshore							
	Mean	460,569		254,562	229,282	98,922	194,255
	95% LL	279,776		119,099	133,469	34,911	95,826
	95% UL	670,104		446,332	338,083	187,721	324,045
Coastwide (S1)							
	Mean	1,248,410	1,137,980	919,328	683,575	537,173	713,359
	95% LL	743,970	686,134	538,281	370,106	257,993	388,793
	95% UL	1,752,850	1,589,826	1,300,375	997,044	816,353	1,037,924
MIGRATION RATE*							***Mean**
WCVI		30.6%		22.9%	27.8%	15.3%	22.0%
Inshore		6.3%		4.7%	5.7%	3.2%	4.6%
WCVI + Inshore		36.9%		27.7%	33.5%	18.4%	27.2%

* Migration rates rounded to 1 decimal place but sums and 2008-2010 means based on non-rounded values.

Table 4. Biomass estimates for the inshore areas representing the cumulative set of PFMA Sub-areas where sardines were caught by purse seine during June 1-August 31 of 2006 to 2010, based on extrapolating mean WCVI survey trawl densities to the size estimates of the inshore areas. Areas used include entire sub-areas and volume estimates are based on a vertical distribution of 30 m to calculate biomass.

			Year	2006	2008	2009	2010
				Mean WCVI survey trawl density (t/ km^3)			
PFMA	**Sub-area**	**km^2**	**km^3**	**759.9**	**420.0**	**378.3**	**163.2**
7	30	20.0	0.6	456.6	252.4	227.3	98.1
8	2, 3, 5, 16	268.1	8.0	6,111.6	3,378.0	3,042.5	1,312.7
9	1, 2, 11, 12	359.1	10.8	8,186.9	4,525.0	4,075.6	1,758.4
10	1, 2, 3, 4, 5, 6, 7, 8, 9, 12	788.7	23.7	17,979.5	9,937.5	8,950.6	3,861.7
12	7, 9, 10, 11, 16, 39	982.2	29.5	22,390.8	12,375.7	11,146.7	4,809.1
	Sub-total	*2418.1*	*72.5*	*55,125.5*	*30,468.5*	*27,442.7*	*11,839.9*
23	3, 5, 6, 7, 8, 9, 10, 11	456.1	13.7	10,396.7	5,746.4	5,175.7	2,233.0
24	2	54.8	1.6	1,248.2	689.9	621.4	268.1
25	6, 8, 9, 10, 11, 12, 13	284.6	8.5	6,487.5	3,585.7	3,229.6	1,393.4
26	1, 2, 3, 4	175.0	5.3	3,989.4	2,205.0	1,986.0	856.9
27	7	76.2	2.3	1,736.2	959.6	864.3	372.9
	Sub-total	*1046.6*	*31.4*	*23,858.0*	*13,186.6*	*11,877.1*	*5,124.3*
	All Sub-areas	**3,464.7**	**103.9**	**78,952.6**	**43,638.0**	**39,304.3**	**16,957.5**

Table 5. Canadian harvest control rule parameters and provisional catch allowances for the fishing season beginning in 2011. Inclusion of inshore areas in the migration term is novel to the assessment process and application in the harvest control rule.

Coastwide adult biomass as of July 2010 is 537,173 tonnes (Hill et al. 2010)			
Region	WCVI	Inshore areas	WCVI+Inshore areas
Average Migration (2008-2010)*	22.0%	4.6%	27.2%
Harvest rate	0.15	0.15	0.15
Provisional 2011 catch option (tonnes)	17,725	3,667	21,917

* Migration rates rounded to 1 decimal place but sums and 2008-2010 means based on non-rounded values.

Table 6. Data and modelled results demonstrating the use of an alternative harvest control rule that applies a 15% harvest rate to a given year's biomass estimate to set a TAC for the subsequent fishing season. Underlined results correspond to use of a 2007 biomass estimate that was linearly interpolated from relationship shown in Figure 6. All biomass and catch amounts in tonnes.

A. Based on current biomass estimates for the WCVI core survey region.

Year	WCVI biomass estimate	Modelled TAC= Modelled catch (WCVI biomass of Year-1 x 0.15)	Modelled harvest rate Modelled catch / WCVI biomass estimate
2006	381,617		
2007	<u>345,400</u>	57,243	*16.6%*
2008	210,924	<u>51,810</u>	<u>24.6%</u>
2009	189,977	31,639	16.7%
2010	81,964	28,497	34.8%
2011		12,295	

B. Based on current biomass estimates for the WCVI core survey region and for the inshore areas (IA) combined.

	WCVI +IA biomass	Modelled TAC= Modelled catch (WCVI biomass of Year-1 x 0.15)	Modelled harvest rate Modelled catch / WCVI biomass estimate
Year	WCVI	WCVI	WCVI + Inshore
2006	460,569		
2007	<u>416,860</u>	69,085	16.6%
2008	254,562	<u>62,529</u>	<u>24.6%</u>
2009	229,282	38,184	16.7%
2010	98,922	34,392	34.8%
2011		14,838	

Table 7. Total allowable catch (TAC) amounts, harvests, and biomass estimates for B.C. and the U.S. Observed annual sardine harvests in B.C., Washington and Oregon combined, and U.S states (Washington, Oregon and California) during 2006-2010. Also shown are the total allowable catches (by nation) and current biomass estimates by region(s) within B.C. (core WCVI survey region without and with inshore areas (IA) and coastwide.

	TAC		Harvest			Biomass		
Year	B.C.	U.S.	B.C.	WA+OR	U.S.	WCVI	WCVI+ IA	Coastwide
2006	13,500	118,937	1,558	39,747	90,776	381,617	460,569	1,248,410
2007	19,800	152,564	1,524	46,715	127,695	**328,718*	**396,726*	1,137,980
2008	12,491	89,093	10,435	29,375	87,175	210,924	254,562	919,328
2009	18,196	66,932	15,334	29,507	67,084	189,977	229,282	683,575
2010	23,166	72,039	*20,000*	*32,168*	*63,301*	81,964	98,922	537,173

*2007 biomass estimate (and mean density) interpolated from relationship shown in Figure 6.
2010 harvests are in-season estimates (as of ~December 1, 2010).

Table 8. Estimates of realized harvest rates for B.C. and U.S regions based on current biomass and coastwide estimates. Also shown are realized percentages of each country's total allowable catch that was harvested.

Year	WCVI B.C.	WCVI+ IA B.C.	B.C. Coastwide	WA+OR Coastwide	U.S.+B.C. Coastwide	U.S. Coastwide	B.C. TAC	U.S. TAC
2006	0.4%	0.3%	0.1%	3.2%	7.4%	7.3%	11.5%	76.3%
2007	*0.5%*	*0.4%*	0.1%	4.1%	11.4%	11.2%	7.7%	83.7%
2008	4.9%	4.1%	1.1%	3.2%	10.6%	9.5%	83.5%	97.8%
2009	8.1%	6.7%	2.2%	4.3%	12.1%	9.8%	84.3%	100.2%
2010*	***24.4%***	***20.2%***	***3.7%***	***6.0%***	***15.5%***	***11.8%***	***86.3%***	***87.9%***

**2010 harvests are in-season estimates (as of ~December 1, 2010).*

Table 9. Modelled scenarios showing effects on the coastwide (U.S.+B.C.) realized harvest rate (HR) from applying a 15% target harvest rate to each of the U.S. and Canadian harvest control rules (HCR). All abundance and total allowable catch (TAC) amounts are in tonnes.

	HCR INPUT					TAC			REALIZED HR		
Year	Coastwide Biomass	Target HR	US Distn	BC Mign	US Cutoff	US	BC	US+BC	US to Coastwide	BC to Coastwide	US+BC to Coastwide
High	3,000,000	15%	87%	20%	150,000	371,925	90000	461925	12.4%	3.0%	15.4%
2006	1,248,410	15%	87%	20%	150,000	143,343	37452	180795	11.5%	3.0%	14.5%
2008	919,328	15%	87%	20%	150,000	100,397	27580	127977	10.9%	3.0%	13.9%
2009	683,575	15%	87%	20%	150,000	69,632	20507	90139	10.2%	3.0%	13.2%
2010	537,173	15%	87%	20%	150,000	50,526	16115	66641	9.4%	3.0%	12.4%
Low	300,000	15%	87%	20%	150,000	19,575	9000	28575	6.5%	3.0%	9.5%
High	3,000,000	15%	87%	40%	150,000	371,925	180000	551925	12.4%	6.0%	18.4%
2006	1,248,410	15%	87%	40%	150,000	143,343	74905	218247	11.5%	6.0%	17.5%
2008	919,328	15%	87%	40%	150,000	100,397	55160	155557	10.9%	6.0%	16.9%
2009	683,575	15%	87%	40%	150,000	69,632	41015	110646	10.2%	6.0%	16.2%
2010	537,173	15%	87%	40%	150,000	50,526	32230	82756	9.4%	6.0%	15.4%
Low	300,000	15%	87%	40%	150,000	19,575	18000	37575	6.5%	6.0%	12.5%
High	3,000,000	15%	87%	60%	150,000	371,925	270000	641925	12.4%	9.0%	21.4%
2006	1,248,410	15%	87%	60%	150,000	143,343	112357	255699	11.5%	9.0%	20.5%
2008	919,328	15%	87%	60%	150,000	100,397	82740	183137	10.9%	9.0%	19.9%
2009	683,575	15%	87%	60%	150,000	69,632	61522	131153	10.2%	9.0%	19.2%
2010	537,173	15%	87%	60%	150,000	50,526	48346	98872	9.4%	9.0%	18.4%
Low	300,000	15%	87%	60%	150,000	19,575	27000	46575	6.5%	9.0%	15.5%
High	3,000,000	15%	87%	20%	0	391,500	90000	481500	13.1%	3.0%	16.1%
Low	300,000	15%	87%	20%	0	39,150	9000	48150	13.1%	3.0%	16.1%
High	3,000,000	15%	87%	40%	0	391,500	180000	571500	13.1%	6.0%	19.1%
Low	300,000	15%	87%	40%	0	39,150	18000	57150	13.1%	6.0%	19.1%
High	3,000,000	15%	87%	60%	0	391,500	270000	661500	13.1%	9.0%	22.1%
Low	300,000	15%	87%	60%	0	39,150	27000	66150	13.1%	9.0%	22.1%

Table 10. Biomass indices (tonnes) used in the coastwide assessment to calibrate biomass estimates as reported in Hill et al. (2010). DEPM = Daily Egg Production Model, TEP =Total Egg Production.

	Spring observations				Summer observations	
Calendar Year	DEPM Mean	DEPM SE *ln*(index)	TEP Mean	TEP SE *ln*(index)	Aerial Mean	Aerial SE ln(index)
2006			651,994	0.25		
2007	198,404	0.30	306,297	0.26		
2008	66,395	0.27	128,118	0.21		
2009	99,162	0.24	162,188	0.22	1,236,910	0.90
2010	58,477	0.40	97,838	0.29	173,390	0.40

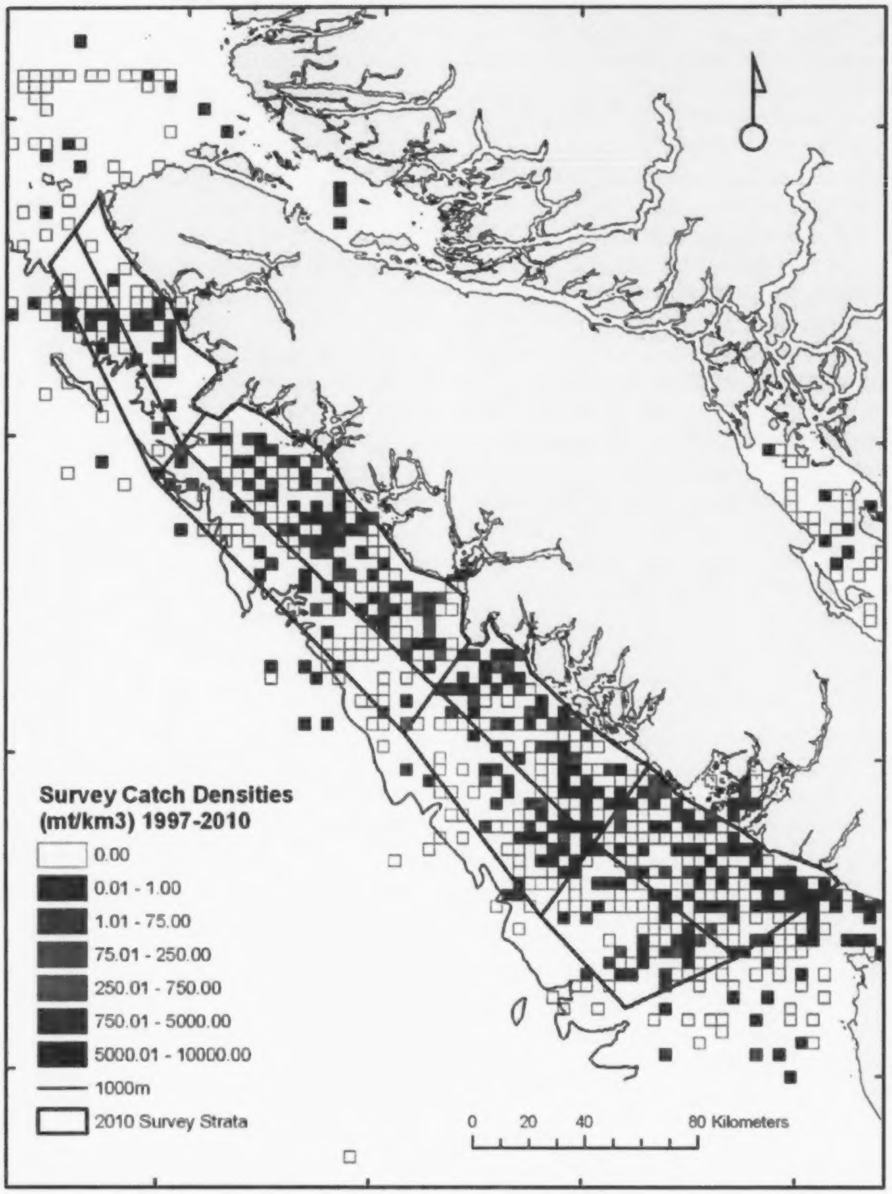

Figure 1. Mean sardine densities for all 1997-2010 sardine survey trawl tows based on 4x4 km sized grid cells. Outer boundaries define the core WCVI survey region. Also shown are sub-regional boundaries as they pertain to future work interests for stratification schemes. Coordinates and spatial information included in an Appendix.

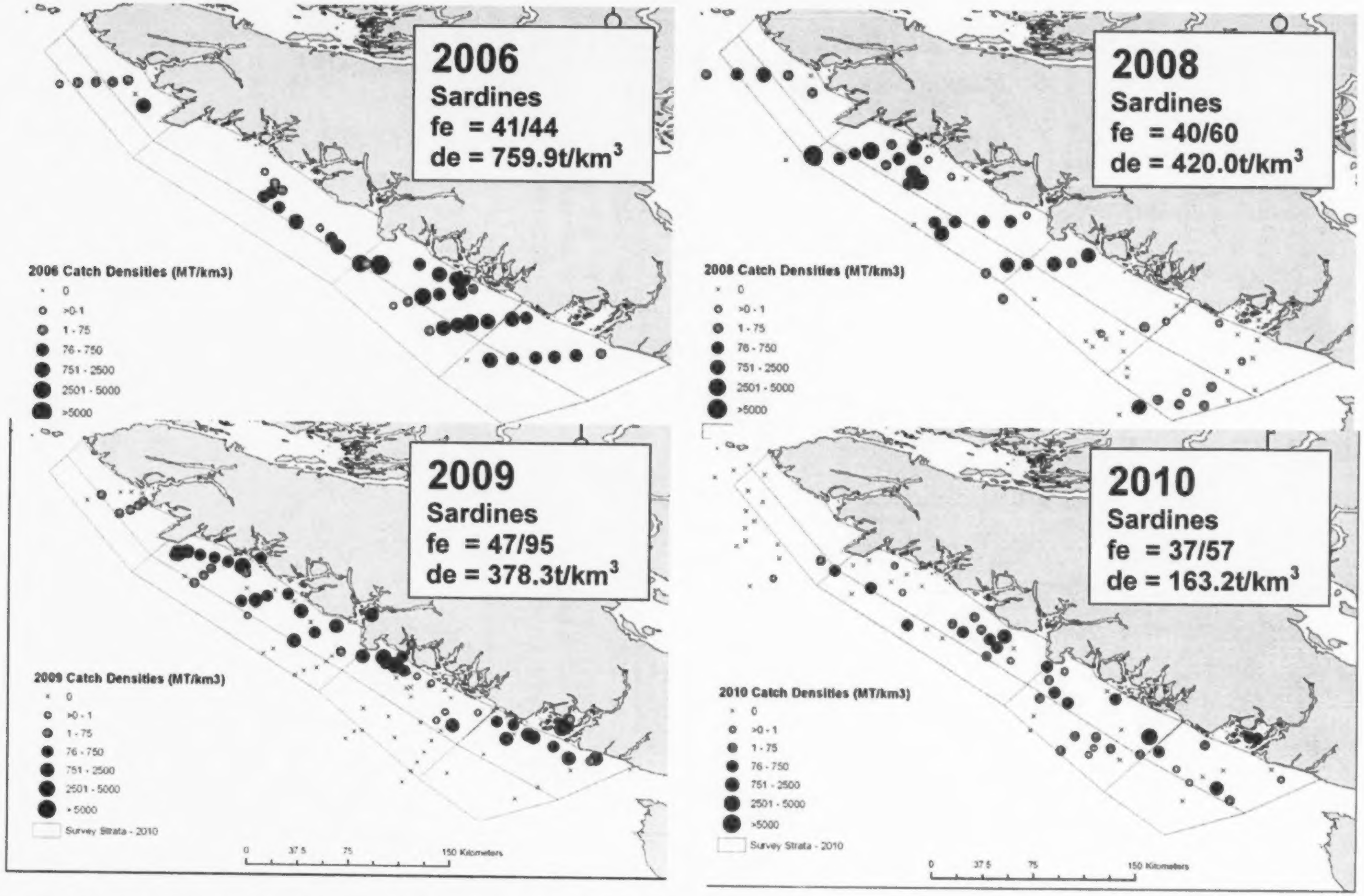

Figure 2. Sampling locations and relative catch densities for 2006, 2008-2010 WCVI sardine summer trawl surveys. By year, the fraction (fe) of positive sardine tows of the effective sample size and the mean density (de) associated with the core region are shown.

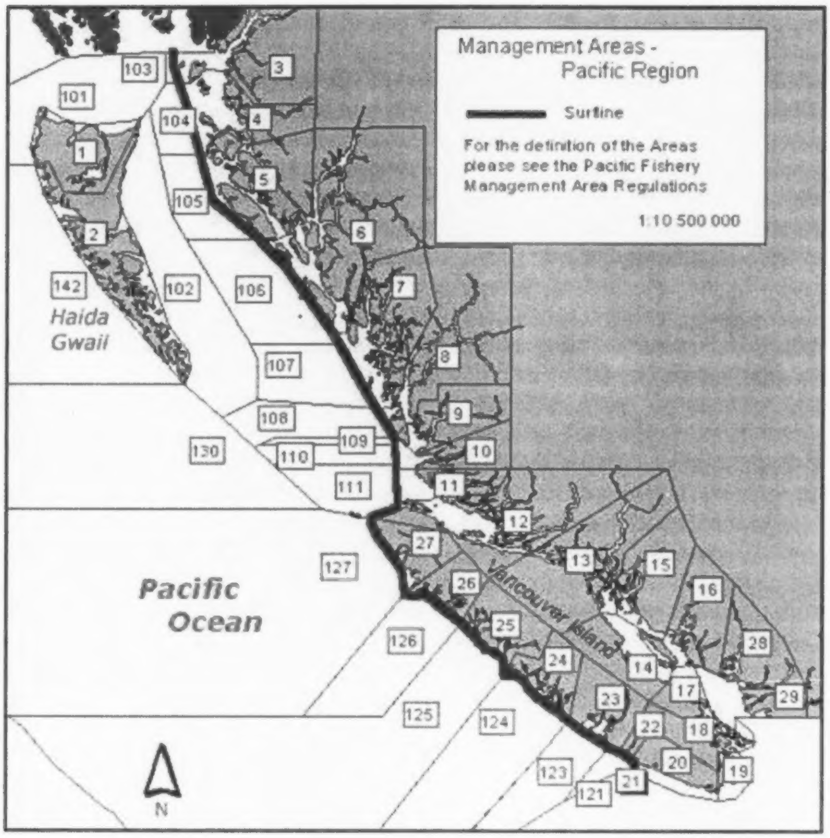

Figure 3. Pacific Fishery Management Areas of Fisheries and Oceans Canada.

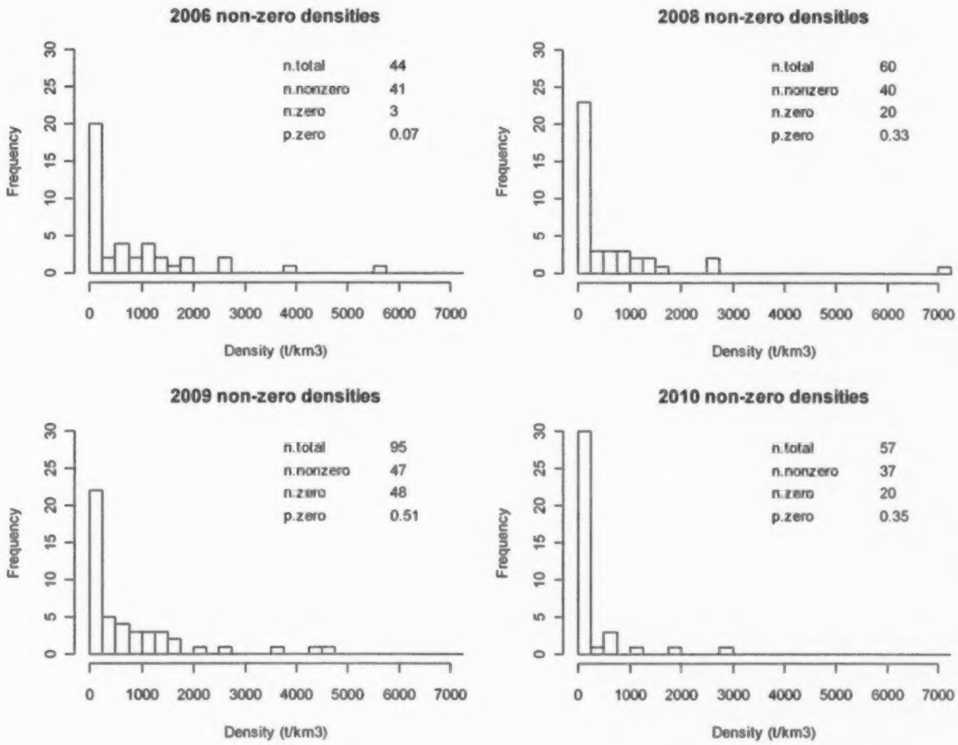

Figure 4. Histograms of non-zero sardine survey catch densities and summary statistics representing the core WCVI survey region in 2006 and 2008-2010. Legend coding: n.total=effective sample size, n.nonzero= number of samples with sardines in catch;; n.zero= number of samples with no sardines in catch; p.zero=proportion of samples with no sardines in catch.

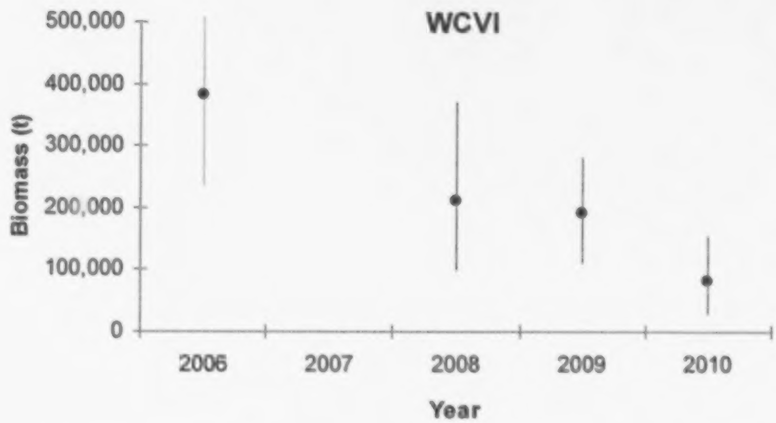

Figure 5. West coast of Vancouver Island mean biomass estimates for core survey region (and 95% confidence intervals) for 2006 and 2008 to 2010

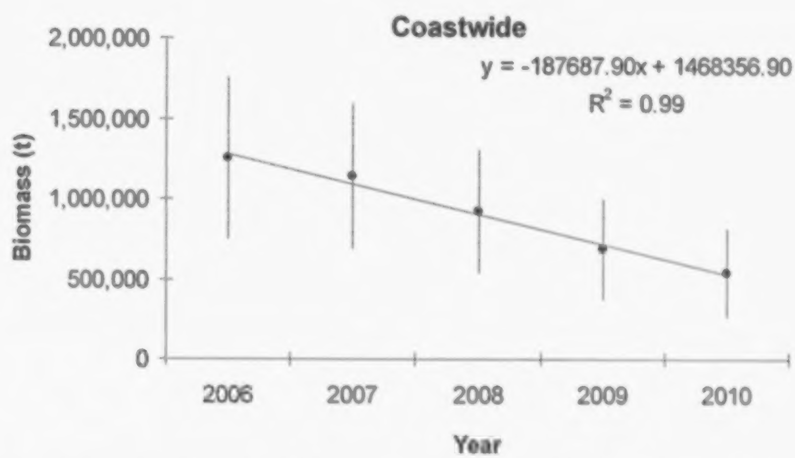

Figure 6. Coastwide mean adult biomass estimates (and 95% confidence intervals) for 2006 to 2010 (linear regression: R^2=0.99, p=0.003), based on Hill et al. (2010) for semester 1 (July 1) age 1+ sardines.

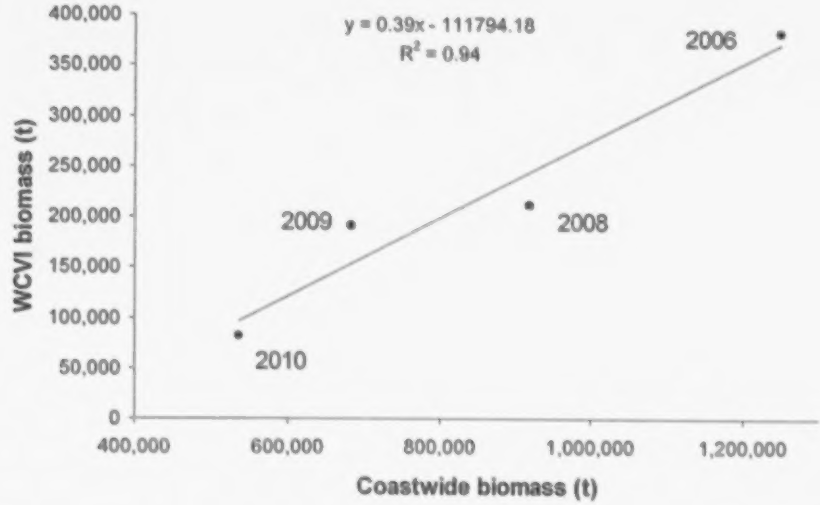

Figure 7. West coast of Vancouver Island mean biomass estimates for core survey region plotted against coastwide biomass estimates, for 2006 and 2008 to 2010 (linear regression: R^2=0.94, p=0.03).

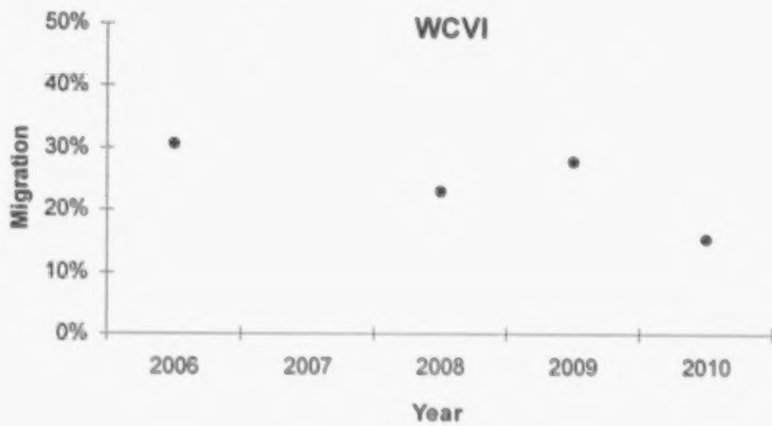

Figure 8. West coast of Vancouver Island migration rate estimates based on core survey region for 2006 and 2008-2010.

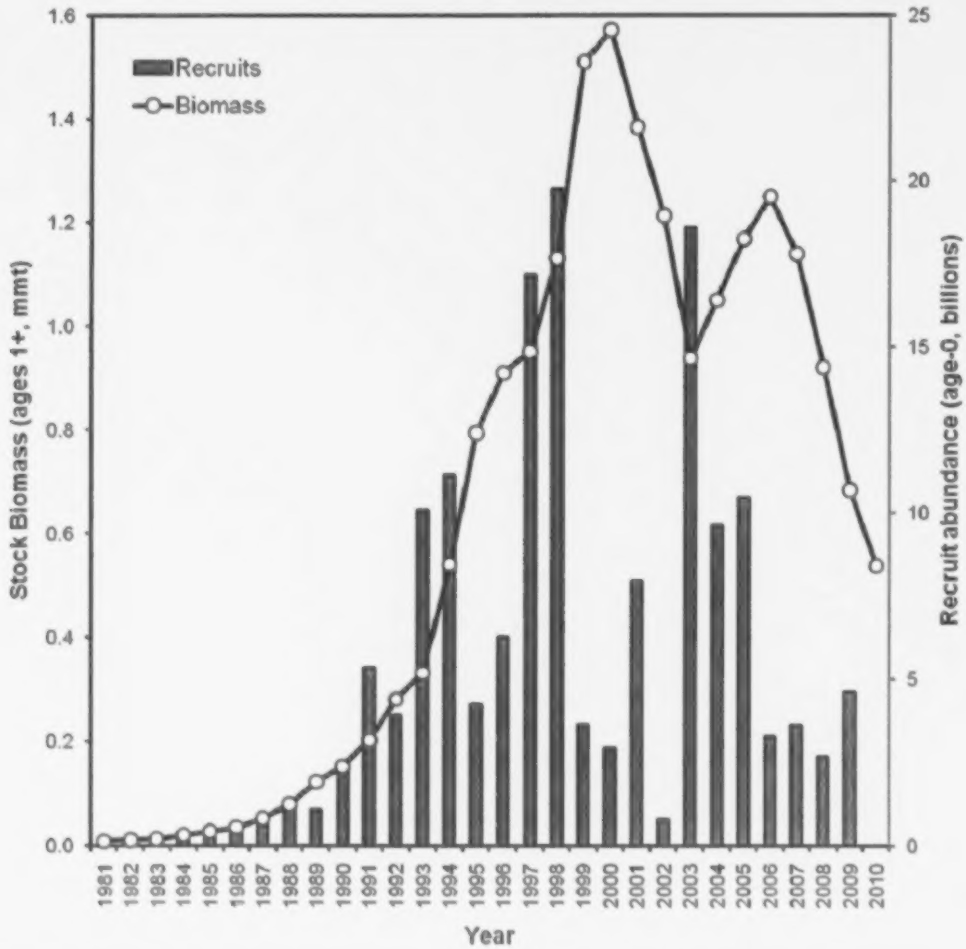

Figure 9. Abundance trends for age 1 recruits (by year class) and adult coastwide biomass. Information from Hill et al. (2010, Figure 40).

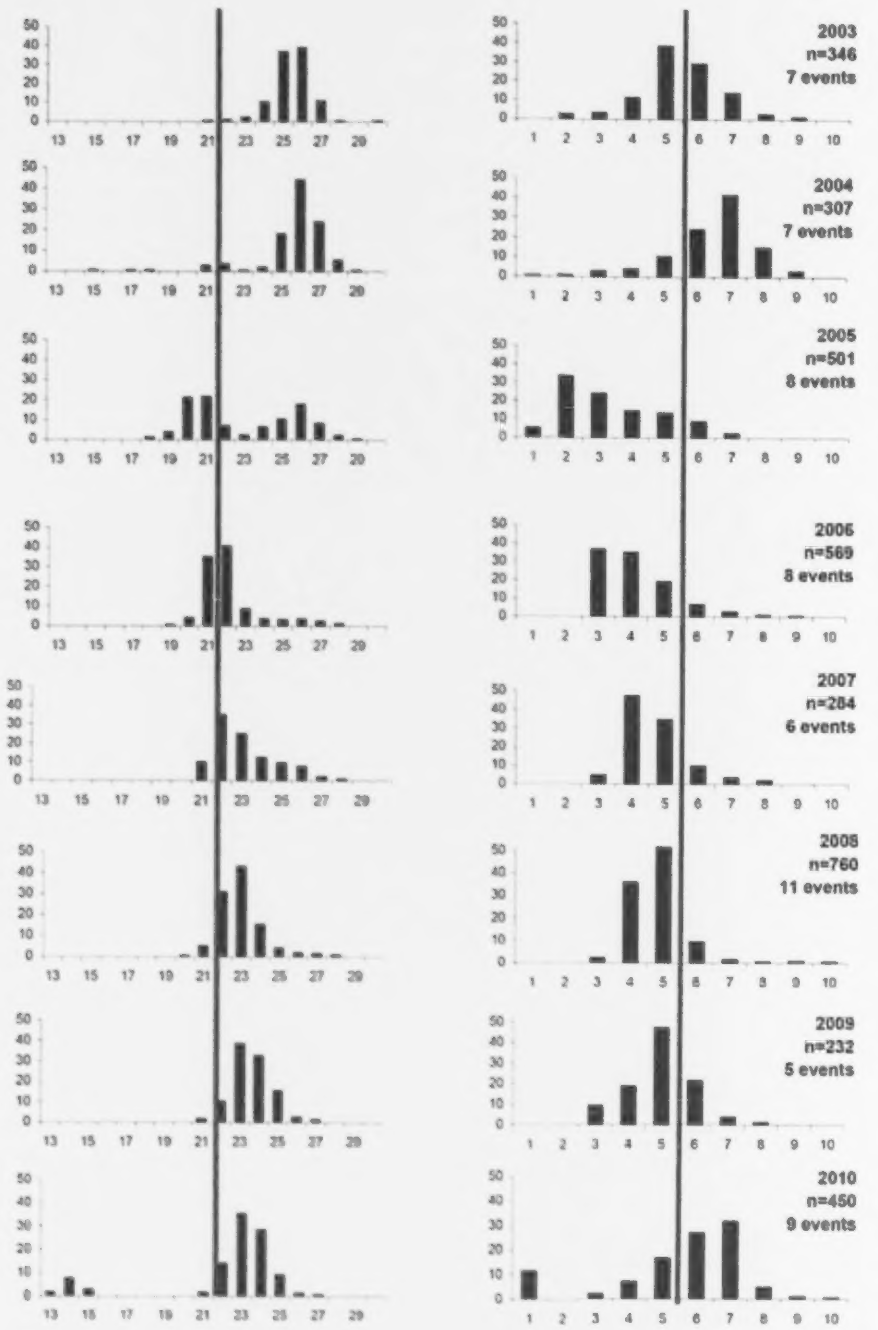

Figure 10. Length and age frequency distributions from sardine samples collected during WCVI surveys in 2003 to 2006 and 2008 to 2010 and from inshore commercial seine catches during 2004 and 2007. Lines between 21 and 22 cm and 5 and 6 years provided to help visual comparison. n = number of fish sampled, events = number of fishing events in each sample.

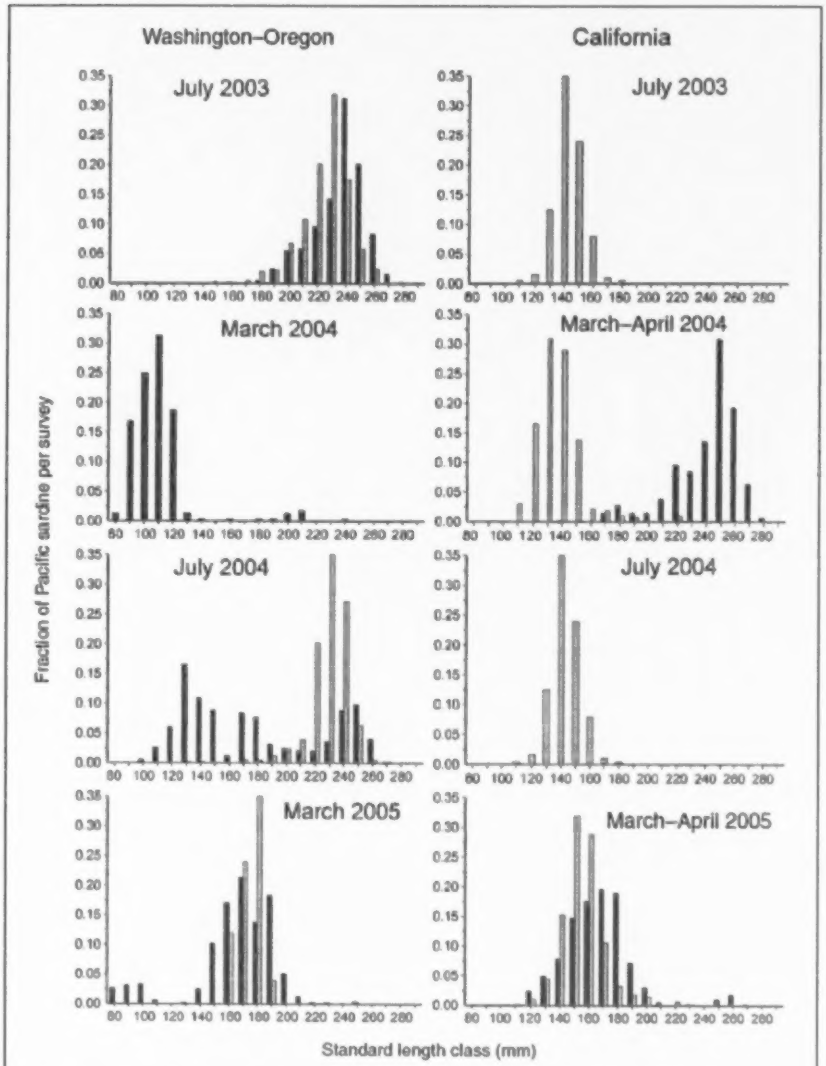

Figure 11. Standard lengths (mm) of sardines collected during 2003 to 2005 off Washington-Oregon and Central-Southern California coasts from July or March-April research trawl surveys (black bars) or commercial purse seine port samples (gray bars). Information from Lo et al. (2010, Figure 6).

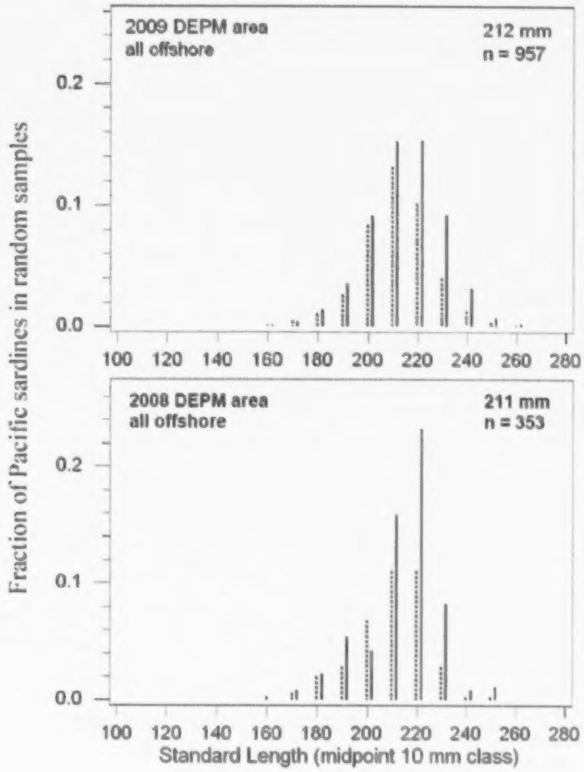

Figure 12. Standard lengths (mm) of sardines collected in 2008 and 2009 off central-southern California coasts during March-April spawning associated with Daily Egg Production Method (DEPM) surveys. Males indicated by dotted bars and females by solid bars. Means and sample sizes noted in top right corners. Information from Lo et al. (2009, Figure 7).

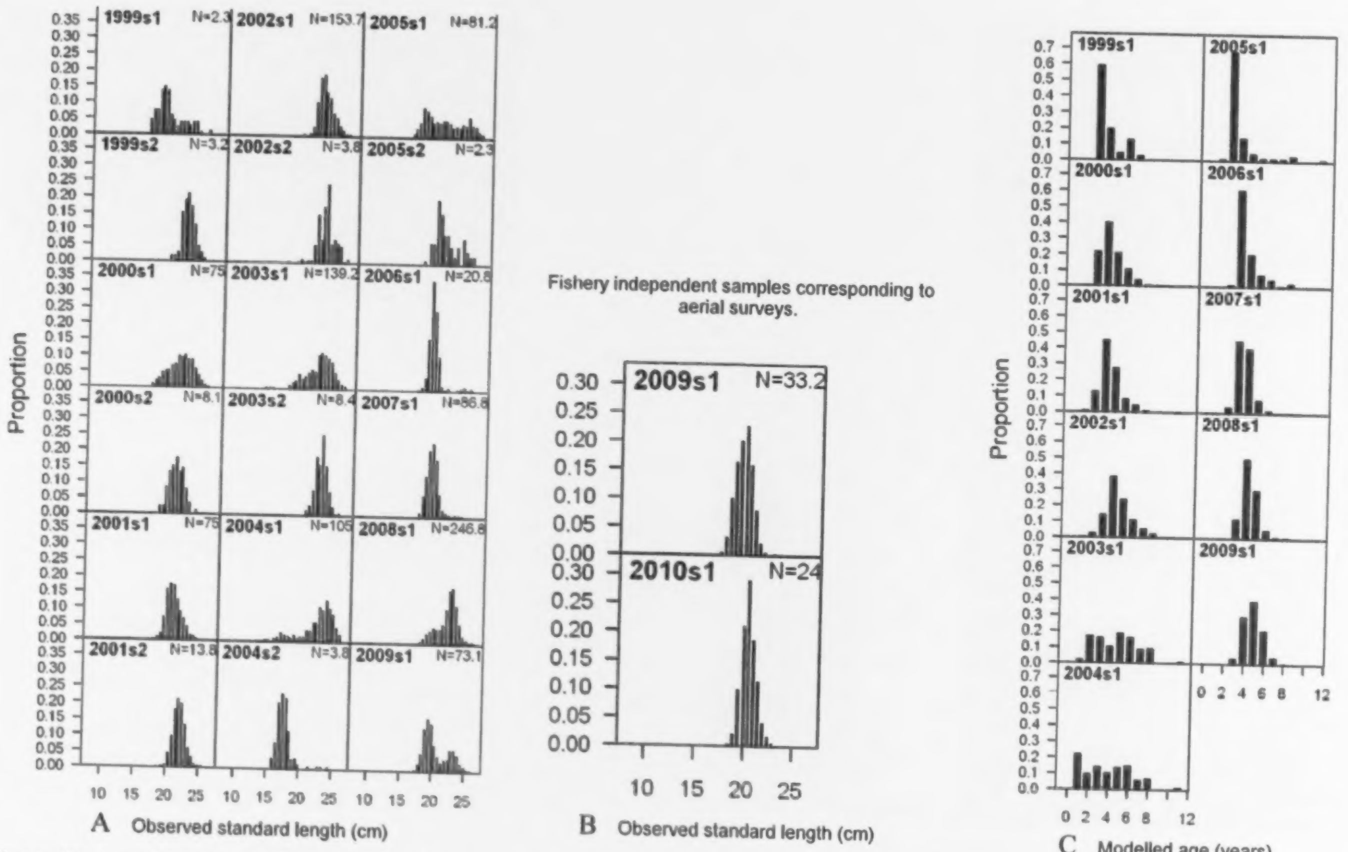

Figure 13. Length and age trends representing: commercial seine catches from B.C., Oregon and Washington combined (A and C), and seine-caught samples from Oregon and Washington associated with 2009 and 2010 aerial surveys (B). Information from Hill et al. (2010, Figures 5f, 6f and 13); "s1" represents summer and autumn and "s2" represents winter and spring. N represents effective sample size.

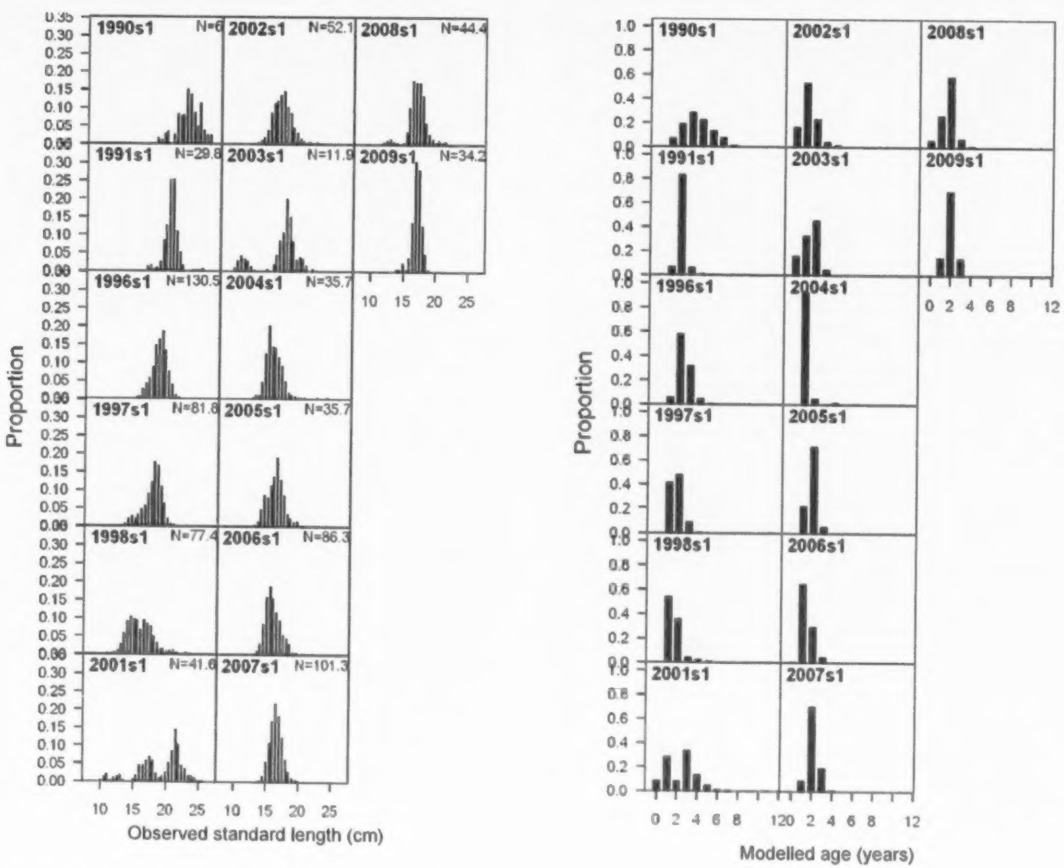

Figure 14. Length and age trends representing summer and autumn (s1) commercial seine catches from Central California. Information from Hill et al. (2010, Figures 5d and, 6d). N represents effective sample size.

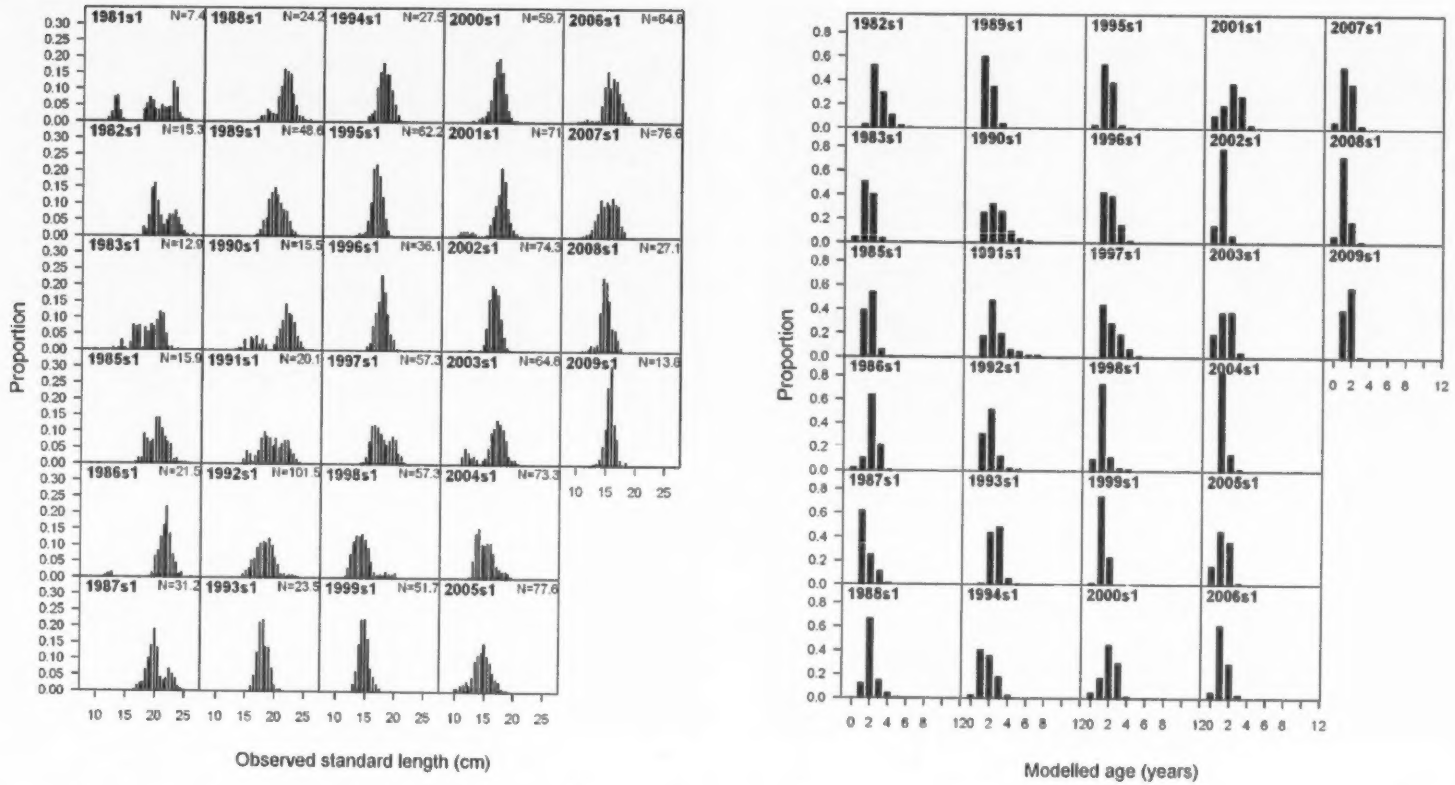

Figure 15. Length and age trends representing summer and autumn (s1) commercial seine catches from Southern California. Information from Hill et al. (2010, Figures 5b and, 6b). N represents effective sample size.

APPENDIX

WCVI survey core survey region boundary coordinates and sub-regional coordinates (decimal degrees) as they pertain to future work interests for stratification schemes, regional and sub-regional size representation, and information corresponding to Figure 1.

Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
48.614	-124.763	49.382	-126.545	49.989	-127.980
48.384	-125.257	48.750	-125.937	49.880	-128.107
48.228	-125.786	49.236	-126.705	50.768	-128.43
48.99	-125.672	49.094	-126.859	50.655	-128.543
48.750	-125.937	50.092	-127.863	50.55	-128.663
48.518	-126.192				

Stratum	Area (km^2)	Volume (km^3)	Proportion of region
A	4506.70	135.20	0.27
B	4231.58	126.95	0.25
C	5528.69	165.86	0.33
D	2473.11	74.19	0.15
Southwest	3910.03	117.30	0.23
Southeast	4828.25	144.85	0.29
Northwest	3287.04	98.61	0.20
Northeast	4714.76	141.44	0.28
All	**16,740.08**	**502.20**	**1.00**